

**Conserving soil moisture for soybean growth as a climate change adaptation
strategy**

by

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PREFACE

The research contained in this thesis was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by uMngeni Resilience Project of South Africa.

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.



Signed: Professor Albert T. Modi

Date: 7 March 2017

DECLARATION

I, Nomthandazo Maphumulo, declare that:

- (i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;
- (ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;
- (iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;
- (iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
 - a) their words have been re-written but the general information attributed to them has been referenced;
 - b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;
- (v) where I have used material for which publications followed, I have indicated in detail my role in the work;
- (vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;
- (vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: Nomthandazo Maphumulo

Date: 7 March 2017

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ABSTRACT

Low crop productivity among smallholder farmers in rural areas is mainly associated with low and variable rainfall as well as factors such as soil fertility. Climate change projections show that rainfall is going to become more variable and hence a major constraint to rain-fed rural cropping systems. There is a need to assist farmers in these areas to cope with current challenges and develop long-term adaptation to climate change. Therefore, the aim of this study was to evaluate the use of soil water conservation strategies and nitrogen fixing legumes as part of climate smart agricultural practices. Specifically, the study evaluated the effect of mulching and fertiliser levels on growth and yield of soybean under rain-fed conditions in the Swayimane rural area of KwaZulu-Natal. The experimental design was a split-plot [hay-mulch (HM) and non-mulch (NM)] arranged in randomised complete blocks (0%, 50% and 100% of recommended fertiliser) replicated three times. Data collected included soil water content, plant height, leaf number, leaf area index (LAI), chlorophyll content index (CCI) and stomatal conductance (SC). Yield and yield components were determined at harvest. The results showed that the use of hay-mulch was effective ($P < 0.05$) in retaining soil water in the root zone. Soil water content in the non-mulched plots frequently reached permanent wilting point hence exposing plants to intermittent water stress. However, mulching had no significant effect on plant growth (plant height, LAI) and SC. Highly significant ($P < 0.01$) differences were observed in CCI, with hay-mulch having a higher CCI compared to non-mulch. Interestingly, plants in non-mulched plots had higher ($P < 0.05$) leaf number compared to plants in mulched plots; this was partly due to a fungal disease that affected plants in mulched plots. Consistent with results of growth, there were no differences in yield of soybean plants grown under mulched relative to non-mulched plots. Subsequent to harvesting the soybean, the seeds were subjected to seed quality tests to assess the effect of production environment on seed quality of progeny. Results of seed quality showed highly significant differences ($P < 0.001$) with progeny from non-mulched plots having relatively higher seed quality (germination percentage, mean germination time and germination velocity index). Overall, the study concluded that while mulching was effective in retaining soil water in the root zone, this did not translate to improved growth and yield as well as subsequent seed quality. The lower soil temperatures experienced under mulching may have inadvertently suppressed growth. Further research is still required over several seasons to confirm these findings and develop firm recommendations on the appropriate use of mulch.

TABLE OF CONTENTS

PREFACE.....	i
DECLARATION.....	ii
ACKNOWLEDGMENTS.....	iii
ABSTRACT	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES.....	viii
CHAPTER 1	1
GENERAL INTRODUCTION	1
1.1 Introduction	1
1.2 Rationale of the Project	3
1.3 Justification.....	3
1.4 Aims and Objectives.....	3
1.5 Outline of Thesis	4
References	5
CHAPTER 2.....	7
LITERATURE REVIEW	7
2.1 Climate Change and Variability	7
2.2 Climate Change Impacts on Agriculture	8
2.2.1 Temperature and heat stress	9
2.2.2 Drought stress.....	10
2.2.3 Flash floods, rainfall and variability.....	11
2.2.4 Shifting boundaries for agro-ecological zones and shifting patterns	12
2.3 Climate Change Adaptation	12
2.3.1 Mulching – soil water conservation.....	14

2.3.2 Integrated soil fertility management.....	16
2.3.3 Crop diversification – soybean	17
2.4 Climate Smart Agriculture.....	17
2.5 Conclusion	18
References	19
CHAPTER 3	27
MATERIALS AND METHODS	27
3.1 Plant Material	27
3.2 Study Site Description	27
3.3 Soil and soil water content	28
3.4 Experimental Design	28
3.5 Agronomic Practices.....	29
3.6 Data Collection	29
3.6.1 Weather Data	29
3.6.2 Field Data Collection.....	30
3.6.3 Harvest Data Collection.....	30
3.7 Seed Quality	30
3.7.1 Standard Germination Test.....	30
3.7.2 Seed Water Activity (aW) and grain Moisture Content %	31
3.8 Statistical Analysis	31
References	31
CHAPTER 4.....	32
THE EFFECTS OF MULCH AND FERTILISER USE ON GROWTH, PHYSIOLOGY AND YIELD OF SOYBEAN	32
4.1 Introduction	32
4.2 Results	34
4.2.1 Weather observed	34

4.2.2 Effect of mulching and fertiliser on soil water content	34
4.2.3 Effect of mulching and fertiliser on crop physiology.....	35
4.2.4 Effect of mulching and fertiliser on crop growth	39
4.2.5 Effect of mulch and fertilizer on soybean yield	40
4.3 Discussion.....	40
4.4 Conclusions	44
References	45
CHAPTER 5	48
THE EFFECTS OF MULCH AND FERTILISER USE ON Seed quality of soybean.....	48
5.1 Introduction	48
5.2 Results	50
5.2.1 Initial seed quality	50
5.2.2 Effect of mulch treatment on soybean water activity	51
5.2.3 Effect of mulch on soybean grain moisture %	51
5.2.4 Effect of mulch and fertiliser on soybean germination	52
5.4 Conclusion	56
References	57
CHAPTER 6	59
6.1 General Discussion	59
6.2 Conclusion	60
6.3 Recommendations	60
APPENDICES	61
Appendix 1: ANOVA Tables	61

LIST OF TABLES

Table 4.1: Soybean yield parameters showing the effect of mulch and fertilizer.	40
Table 5.1: Performance of soybean under standard germination test prior to field planting showing mean germination time (MGT), Germination Velocity Index (GVI) and seedling parameters. ...	50
Table 5.2: A comparison of soybean seed quality parameters in response to mulching and fertiliser treatments under germination test showing mean germination time (MGT), germination velocity index (GVI) and seedling parameters.	54

LIST OF FIGURES

Figure 2.1: Variability in seasonal rainfall (i.e., the accumulated amount of rainfall from the planting to the harvest of a crop) is higher in the areas with smaller amount of rainfall (Harvest Choice, 2010).	7
Figure 2.2: Effect of mulching on crop yield (A), water use efficiency (B) and nitrogen use efficiency (C) of wheat and maize. Dots show means, error bars represent 95% confidence intervals (Source: Qin et al., 2015).	16
Figure 3.1: Average monthly temperatures (maximum and minimum) and rainfall distribution for Swayimane over a period of ten years (Bezuidenhout and Singels, 2007).	28
Figure 3.2: Automatic weather station at the trial site.	29
Figure 5.1: Standard germination percentage of soybean for the seed used in the study.	50
Figure 5.2: Effect of mulching treatment on soybean seed water activity.	51
Figure 5.3: Effect of different fertiliser rates on soybean grain moisture (%).	52
Figure 5.4: The effect of mulching treatment and fertiliser rate on the mean germination percentage of soybean.	53

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

It is now recognised that climate change and variability is a reality and sub-Saharan Africa (SSA) is mostly vulnerable to its impacts since its inhabitants are marginalized, poor and food insecure (Corner et al., 2014). Climate change refers to an average continuous change (increases or decreases) in the statistical distribution of long-term weather patterns which lasts for an extended period (decades, century, and millennium) (Shongwe et al., 2014). Climate change is characterised by changes in precipitation patterns, rainfall variability and high temperatures and these have been shown to increase the frequency of drought, floods, and other events ((Huber and Gullede, 2011; Shongwe et al., 2014). Climate variability refers to yearly fluctuations of weather, above or below its average variations in the mean state and other statistics (e.g. standard deviations) observed on a temporal and spatial scale and is beyond that of an individual event (Stocker et al., 2013). Smallholder farming agriculture in SSA is extremely vulnerable to climate change and variability due to its reliance on rain-fed agriculture (Kotir, 2011).

Across SSA, rural agriculture is important and contributes up to 90% of food production under smallholder farming communities (Alliance for a Green Revolution in Africa (AGRA), 2014). Smallholder farmer production systems differ in individual characteristics, farm size (< 2 hectares), resource distribution between food and cash crops, livestock and off-farm activities, their use of external land, simple, low returns; and high seasonal labour fluctuations, with women playing a vital role in production (Alliance for a Green Revolution in Africa (AGRA), 2014). Evidently, most smallholder farmers are characterised as poor, their agricultural productivity is affected by many socio-economic and biophysical constraints. Climate change and variability threatens, further, the productivity and stability of agriculture through its direct and indirect effects on crop growth and quality of crop produce. It, therefore, exacerbates the effects of current production constraints faced by smallholder farming systems (Cline, 2007; Fisher and Snapp, 2014).

Under climate change long term changes in the patterns of temperature and precipitation are expected to shift production seasons, reduce the availability of soil water, increase the prevalence of pest and disease, and alter suitability of existing agro-ecologies for food

production (Lipper, 2010). As such the ability of agriculture to provide for the much-needed food security and improved rural livelihoods is at risk. Ensuring food security requires resilient agricultural systems that are high yielding, essentially, under low input systems and climate uncertainty. There is a need to transform agriculture so that it adapts to climate risk. This can be achieved through improved management and utilisation of available natural resources (e.g. land, water, soil nutrients, and genetic resources).

Adaptation of agriculture to climate change seems to be the most efficient way for farmers to improve food security and livelihood (Komba and Muchapondwa, 2012). Therefore, appropriate interventions need to be done based on prevailing characteristics of smallholder farmers. To implement appropriate interventions, governments need to understand the opportunities, or lack thereof, for agricultural adaptation. Bryan et al., (2009) pointed out several socio-economic, environmental and institutional factors, as well as the economic structure, as key drivers influencing farmers to choose specific methods in Africa and in some specific SSA countries. Related to on-farm productivity studies have shown that agricultural measures such as the use of improved crop varieties, the planting of trees, soil and water conservation, changing planting dates and irrigation can bring about short and long term resilience (Kabubo-Mariara, 2008; Burney et al., 2014). Thus, there is a need to understand the scope of climate change and the drivers of adaptation, particularly amongst smallholder farmers, to craft appropriate adaptation strategies.

In response to the need for agriculture to adapt and mitigate climate change and variability, climate smart agriculture (CSA) has been proposed as a technique to assist farmers to adapt to climate change (Cline, 2007). Climate smart agriculture can enhance agricultural productivity thus promoting food security in the wake of climate change and variability. According to Solomon et al., (2007), CSA consists of proven practical techniques that can be used to mitigate climate change and variability and at the same time not putting pressure or stress on the environment. It encourages best management practices within the context of environment and crop interaction thus promoting the use of all available and applicable climate change solutions in an impact-focused manner.

1.2 Rationale of the Project

Effects of climate change in SSA will mostly be felt through water. Climate change projects indicate declining rainfall in areas that are already dry. Projections also show increased frequency and intensity of rainfall extremes such as droughts and floods accompanied by higher than average temperatures. Already, water is a limiting factor to crop productivity in rural areas as farmers already struggle to cope with mid-season dry spells. Declining rainfall will exacerbate existing stress such as nutrient stress; most rural farmers are located on marginal soils that are inherently infertile. Climate smart agriculture speaks to sustainable intensification under such conditions. In this regard, conservation agriculture techniques such as mulching that allow for improved soil water retention and availability have been proposed.

1.3 Justification

Agricultural production must increase by 70% by 2050 to meet the world's growing demand for food (Meybeck A., Lankoski J., Redfern S., 2012). Climate change is expected to intensify the challenges already facing agricultural systems and without increased investment, productivity is predicted to decline. Increasing productivity will involve reducing the vulnerability of farmers to various types of stress factors such as drought, flooding and biotic stresses, that can potentially harm their operations and production. While farmers might use a multitude of measures to adapt perturbations, the prolonged impacts of climate change could make these less effective and even introduce new challenges that could further affect already vulnerable communities. Introductions of new techniques are more readily adopted if adapted to local conditions (Talathi, M.S., Mandavkar, 2013).

1.4 Aims and Objectives

The aim of the study was to determine the effectiveness of mulching and fertiliser management in relation to improved soil water conservation and crop productivity under dryland conditions typical of smallholder farming conditions. The specific objectives of the study were therefore:

- To determine the effect of using a grass mulch on soil water content, growth and yield of soybean; and
- To determine the effect of different fertiliser levels on growth and yield of soybean under dryland conditions.

1.5 Outline of Thesis

The outline of the thesis is as follows:

Chapter 1 provides the introduction, background and conceptualisation of the study. It is an introduction of the status of climate change and smallholder farmers in sub-Saharan Africa. It highlights the importance of introducing climate smart agricultural adaption strategies to farmers.

Chapter 2 is the literature review for past studies on smallholder farmers and climate change reports. It focusses on the impacts of climate change, specifically rainfall variability, drought and floods. This chapter further reports on climate smart agriculture adaptation strategies, soil water conservation, crop diversification and integrated soil fertility management.

Chapter 3 reports on the materials and methods used in conducting the study. It summarises the methodology for the whole thesis. Subsequent chapters therefore only report on results without duplication of the methods and materials used.

Chapter 4 reports on the field trial results on the effects of grass mulch and fertiliser. It addresses the objectives of determining the effect of using grass mulch on soil water content, growth, physiology, yield of soybean and the effect of using different fertiliser levels on growth and yield of soybean.

Chapter 5 reports on results of seed quality assessment in response to production environment. Seed quality was evaluated using the standard germination test, seed water activity and grain moisture.

Chapter 6 is a general discussion on the two previous chapters highlighting on the major findings on the effects of using grass mulch and different fertiliser levels as an adaptation strategy in conserving soil moisture and improved soybean production. Finally, this chapter offers concluding statement and recommendations for future studies.

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CHAPTER 2

LITERATURE REVIEW

2.1 Climate Change and Variability

Climate is a complex and interactive system composed of the atmosphere, land surface, snow and sea ice and the oceans (Trenberth et al., 2000; Parry et al., 2007) (Fig 2.1). The terms “weather” and “climate” are loosely defined and intertwined. Climate is generally described in relation to the mean and variability of temperature, precipitation and wind over a certain period, ranging from months to millions of years; the classical period is 30 years (Solomon et al., 2007; Dube et al., 2013). Weather as we experience it, is the daily fluctuation of the atmosphere around us characterised by elements such as temperature, wind, precipitation, cloudiness, humidity and other weather elements (Trenberth et al., 2000; Stocker et al., 2013). Weather has a great influence on rural agricultural farming systems as it exists as part of the daily experience for smallholder farmers with limited adapting resources (Parry et al., 2007).

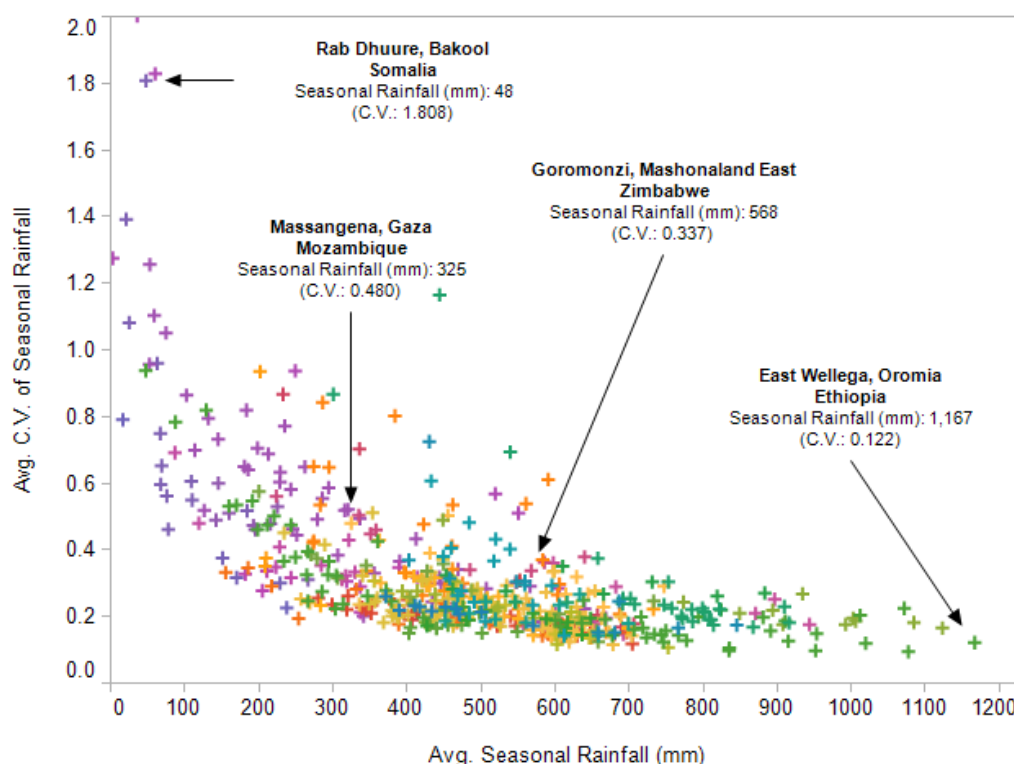


Figure 2.1: Variability in seasonal rainfall (i.e., the accumulated amount of rainfall from the planting to the harvest of a crop) is higher in the areas with smaller amount of rainfall (Harvest Choice, 2010).

Rainfall variability from season to season greatly affects soil water available for crop growth, leading to low crop production. In addition, crop production should be focused in areas with high rainfall and low rainfall variability. However, smallholder farming systems can be found in a wide range of environmental and climatic conditions as (Figure 2.1 above), the different season rainfall received by the three different countries in Sub-Saharan Africa region.

A warmer climate will increase the risk of floods and droughts. Climate change projections reported by Burke et al., (2006) showed regions of strong wetting and drying with a net overall global drying trend. As such, the proportion of the land surface in extreme drought, globally, is predicted to increase by a factor of 10 to 30; from 1-3 % for the present day to 30% by the late century. The number of extreme drought events per 100 years and mean drought duration are likely to increase by factors of two and six, respectively, by the late century (Burke et al., 2006). Observed trends in heat, heavy precipitation, and drought in different places are consistent with global warming.

A defining characteristic of many rain-fed agricultural systems is their vulnerability to weather variability. Due to their reliance on rainfall, smallholder farming systems are at risk to rainfall variability (Harvest Choice, 2010). Hence, water availability is the most important factor affecting smallholder farmers in SSA. Most importantly, smallholder farmers that depend solely on rainfall have limited access to resources and this further undermines their household food and income security; this affects their capacity to cope with the changing climate (IFAD, 2013; Harvey et al., 2014). The fluctuations in year-on-year and within season weather have been observed to have an overbearing effect on the ability of farmers to continue to rely on agriculture as a livelihood strategy (Ashok and Sasikala, 2012). This places emphasis on helping smallholder to adapt to climate change whilst also increasing productivity of their cropping systems.

2.2 Climate Change Impacts on Agriculture

Agricultural productivity in SSA is mostly rain-fed and is therefore vulnerable to rainfall variability and long-term climate change (Thomas et al., 2007). Climate change threatens agricultural production through higher and variable temperatures, changes in precipitation patterns and increased occurrences of extreme events like droughts and floods (Beniston et al., 2007). Current changes in temperature patterns and precipitation are expected to shift agro-ecological zones, production seasons and incidence of pests and diseases (Hansen et al., 2011). Moyo et al., 2012 predicts severe effects including reduced crop yields leading to increased risk

of food insecurity, water scarcity, and spread of climate sensitive diseases. This will modify current cropping systems, market trends and micro-economic scale incomes as well as food security of rural households (Edame et al., 2011).

Overall, a large proportion of the cropping area in SSA is projected to see a decrease in length of growing season. At the same time, the probability of season failure is also projected to increase for all SSA (Thornton et al., 2014). This will expose resource poor rural farmers in the region to crop production losses and concomitant losses in revenues from crop sales for those who trade. Changes in the timing of the rainy season, may confound traditional techniques for farmers to determine appropriate planting dates. Several modelling studies have assessed the potential impacts of climate change on agricultural production in SSA, although the projected ranges of shifts in yields for the major crops vary widely (Challinor et al., 2007, 2009). To appropriately predict the impacts of climate change on agriculture requires data, tools and models at a spatial scale of actual production areas.

2.2.1 Temperature and heat stress

Lobell and Gourdji, (2012) stated that global temperature rise consisted of four key factors, namely; (i) increasing temperature, (ii) an intensified hydrological cycle, (iii) increasing CO₂, and (iv) elevated tropospheric O₃. Stocker et al., 2013) also recognised that heat stress was a major threat to global food supply. Heat stress is a condition that is caused by prolonged exposure to above threshold temperatures (Thornton et al., 2014). Heat stress damage is particularly severe when high temperatures coincide with critical crop development stages, particularly the reproductive period.

According to Lobell and Gourdji, (2012), temperature primarily affects crop yields through certain main metabolic pathways. Higher temperatures will accelerate plant growth and development resulting in shorter plant growth duration causing reduced yields. Temperature impacts the rates of photosynthesis, respiration, and grain filling. Plants with a C4 pathway have higher optimum temperatures for photosynthesis than C3 plants; however, even C4 plants show declines in net photosynthesis at above optimum temperatures (Streck, 2005; Yamori et al., 2014). Assuming a constant relative humidity, increase in temperature increases the vapour pressure deficit, between air and the leaf (Will et al., 2013). Plants respond to very high vapour pressure deficit by closing their stomata; however, this is at the cost of reduced photosynthetic rates and an increase in canopy temperature, which in turn may increase heat-related impacts (Lobell and Gourdji, 2012).

Temperature also affects the rate of plant metabolic processes that ultimately influence the production of biomass, fruits and grains by increasing or decreasing photosynthesis-respiration (Amedie, 2013; Bitu and Gerats, 2013). Previous global food assessments have shown that these negative climate change effects are particularly exacerbated in SSA (Parry et al., 2007; Fisher and Snapp, 2014). Earlier flowering and maturity of several crops have been reported in recent decades, often associated with higher temperatures (Challinor et al., 2007). Increases in maximum temperatures can lead to severe yield reductions and reproductive failure in many crops (Komba and Muchapondwa, 2012). In maize, each degree day spent above 30°C can reduce yield by 1.7% under drought conditions (Lobell et al., 2011). Protein content of wheat grain has been shown to respond to changes in the mean and variability of temperature and rainfall (Changnon et al., 2000) specifically, high-temperature extremes during grain filling can affect the protein content of wheat grain. Currently, there is a lack of understanding on the distribution and intensity of crop damage caused by heat stress.

Temporally, the choice of planting dates (i.e. time of sowing and harvesting) and the rate of crop development influence the exposure to extreme temperatures during critical phenological stages (Lobell and Gourdj, 2012; Bitu and Gerats, 2013). To assess heat stress risk, it is then necessary to consider the timing, frequency and extent by which crop-specific temperature thresholds are exceeded during critical crop development stages (Semenov and Shewry, 2011). There is still much to be understood with respect to how crop quality might change as it is affected by new extreme temperature changes. Failure to take quality into account could negatively impact human, livestock nutrition and health. Thus, there is a need to develop and pilot strategies that can help farmers adapt to the threat of increasing temperatures (Komba and Muchapondwa, 2012).

2.2.2 Drought stress

Climate change projections have highlighted SSA as the epicentre for increased incidence of drought (Yin and Li, 2001; Fisher and Snapp, 2014). Drought affects all parts of our environment and livelihoods, often creating economic and financial difficulties for rural smallholder farmers in developing countries. Different drought definitions exist depending on who is affected and as to how they are affected. Drought can be defined according to meteorological, agricultural, hydrological, and socio-economic criteria (FAO, 2013). Agricultural drought, which is important to farmers, is when there is insufficient soil moisture

to meet the needs of a crop at a time (FAO, 2013). This usually occurs due to meteorological drought.

Crops experience water stress when water supply to their roots becomes limiting or when the transpiration rate outstrips rate of water supply from the roots; this is primarily caused by soil water deficit such as drought (Amthor, 2012). Drought stress affects plants at different levels of organization. According to (Lisar et al., 2012), water stress induced by drought reduces the plant cells' water potential and turgor pressure. This often leads to growth retardation and reproduction failure. When plants are initially exposed to water stress, Xu et al., (2010) observed a reduction in stomatal conductance (stomata closure), which limits gaseous exchange, reduces transpiration and arrests photosynthesis. In turn, this will reduce carbon assimilation and ultimately yield formation reducing overall crop yields. Shongwe et al., (2014) reported that drought stress reduced soil fertility by reducing the organic components of the soil as the amount of crop residues is reduced, increasing farming cost for farmers since they will need to add more fertiliser to complement the nutrients lost. An expansion of irrigation is a likely response in some regions, although many areas lack irrigation infrastructure, and water access can often be reduced or limited during periods of severe drought. Under these conditions, adaptation strategies should focus on improving rain water harvesting and conservation for improved water productivity under rain-fed systems.

2.2.3 Flash floods, rainfall and variability

Predictions also show that, other than drought, there will be an increased frequency of floods with most rainfall falling in brief and intense incidences in-between dry spells (Cline, 2007). A flash flood is a rapid flooding of low lying areas mainly caused by heavy or excessive rainfall in a short period, generally less than six hours. Flash flooding occurs when precipitation falls rapidly on saturated soil or dry soil that is poorly drained (Hillel, 2012; Shongwe et al., 2014). As precipitation, may become more intense but less frequent and in some places, bring about longer dry spells, flash floods and runoff are more likely to increase, which might result in increased soil erosion and reduced soil moisture, both impacting food production and livelihoods of resource poor farmers (Khan et al., 2012). Currently, due to lack of rain water harvesting and conservation strategies in rural cropping systems, much of this rainfall is lost. Along with runoff, erosion of the top soil also leads to carbon erosion hence negatively affecting the fertility status of soils (Veitzer and Gupta, 2001). Strategies such as mulching could help reduce runoff losses and erosion whilst also increasing the portion that is drained into the soil.

According to Shongwe et al. (2014), rainfall frequency, distribution and intensity have changed. Rainfall is poorly distributed throughout the growing season, such that there is often no rain during the maturity stage of most crops. This results in crop failure even if the crop has been performing well during the early stages of development. Similarly, long dry periods have been observed during the planting season because of changing rainfall patterns which affect plant growth and eventually crop yield. This further emphasises the need to harvest and conserve rainfall in the field so that it remains available in the soil to support crop growth during dry spells.

2.2.4 Shifting boundaries for agro-ecological zones and shifting patterns

An agro-ecological zone (AEZ) is a geographical land area resource mapping unit that exhibits similar climatic conditions that determine its ability to support rain-fed agriculture and has specific range of potentials and constraints for cropping (Caldiz et al., 2001; Schmidhuber and Tubiello, 2007). Agro-ecological zones are used to determine crop water requirements and long-term frost protection measures among other things (Mugandani et al., 2012). The shifting patterns of AEZs are being driven by climate change with studies confirming crop suitability shifts (Horn et al., 2008; Lin et al., 2013). Streck, 2005, reported that one of the impacts of climate change would be reduced land area suitable for the world's major crops. Current farming systems will be destabilized especially in developing regions like SSA (FAO, 2009; Seneviratne et al., 2012). Currently, farmers have adapted by growing improved crops and raising better tolerant livestock in the case of animal husbandry. In this regard, crop diversification could help farmers adapt to shifting AEZs by introducing new crops to occupy new ecological niches.

2.3 Climate Change Adaptation

Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Folland et al., 2001). Adapting entails taking the right measures to reduce the anticipated negative effects of climate change by making appropriate adjustments and changes. According to the (UNFCCC and Change, 2007), adaptation involves coping with climatic change taking measures to reduce the negative effects, or exploit the positive ones, by making appropriate adjustments. There is no single way to adapt to the impacts of climate change. Experience shows that measures are most effective when local communities are involved from

the start in planning and implementing changes (FAO, 2013). Adaptation should be in synergy with resilience, resilience being the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (Meybeck et al., 2012).

Various types of adaptation strategies exist and can be grouped into autonomous or private and planned or public strategy (Lim et al., 2005; Fankhauser and Soare, 2012). Private strategies involve action taken by non-state agencies such as farmers, communities or organisations in response to climate change. From several studies in SSA, strategies adapted by smallholder farmers include drought tolerant varieties, crop choice or selection, irrigation, and crop-rotation, mulching, and intercropping (Thomas et al., 2007; Shongwe et al., 2014). Autonomous strategies (also called spontaneous) is adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems (Parry et al., 2007; Tompkins et al., 2010). Examples of autonomous strategies include changes in crops grown or different harvest and planting/sowing dates. Planned adaptation, according to Folland et al., 2001 definition, is “the result of a deliberate policy decision, based on awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.” Examples include deliberate crop selection and distribution strategies across different agro-ecological zones, substitution of new crops for old ones and resource substitution induced by scarcity (Meybeck A., Lankoski J., Redfern S., 2012; Etwire et al., 2013) and planned adaptations can be either reactive or anticipatory. Reactive adaptation is defined as the ability to adapt one’s body to any environment or situation and includes strategies such as use of improved crop varieties, migration to other ecological zones and ecosystems. Human system adaptation can be motivated by private or public interest, that is who adapts. Private decision makers include individuals, households, businesses, and corporations; public interests are served by governments at all levels. Anticipatory adaptation (also called proactive adaptation) is an adaptation that takes place before impacts of climate change are observed examples include use of drought resistant varieties.

Several practical options for adaptation exist ranging from technological to behavioural, and these must be refined, augmented and deployed appropriately listed some of these options:

- i. Intensification of food production by smallholders through better access to improved seed, soil fertility management (e.g., fertiliser application) and reliable water supply;

- ii. Improved agricultural water management (smallholder irrigation, rainwater harvesting, sustainable extraction of groundwater and other underutilized water resources), conservation agriculture and improved on-farm water use efficiency;
- iii. Shifts towards crop and livestock types/varieties/breeds with greater drought and heat tolerance and improved pest and disease resistance;
- iv. Enterprise diversification towards higher value crops, value adding (processing), off-farm employment, and marketing infrastructure;
- v. Grain storage improvements (from household to national levels) to ensure security of carryover stocks and access to surpluses;
- vi. Climate forecasting and provision of timely advice to governments, private sector (agro-dealers), extension services and farmers; and
- vii. Weather-related crop and livestock insurance.

2.3.1 Mulching – soil water conservation

The impacts of climate change on agriculture in SSA are mostly associated with the sensitivity of rain-fed agriculture to drought and mid-season dry spells. A response to this has been soil water conservation techniques that encourage infiltration, reduce runoff and reduce soil evaporation (Giller et al., 2009). These techniques emphasise the need to conserve or retain water in the soil, make it available to the crop and hence minimise the effect of dry spells. Soil water conservation techniques include contour furrows, strip cropping, ridging, crop rotation, planting of trees, mulching, contour cultivation, grass strips and use of organic matter (Dörlochter-Sulser and Nill, 2012).

Thierfelder et al. (2015) assessed the effect of long-term no tillage, crop rotation and straw mulching on maize grain yield. It was found that mean maize yield was 1 ton per hectare higher with conservation agriculture practices (with straw mulching) when mean annual rainfall was below 600 mm. However, when mean annual rainfall was above 1000 mm, soil water conservation techniques may have lower yields of about 1 ton per hectare. Qin et al., (2015) reported that crop yields increased by 7.3% under rain-fed agriculture in dry climates when no-tillage, straw mulching and crop rotation are implemented together. No-till applied alone (without straw mulching and crop rotation) reduced yields by 11.9%. Furthermore, effects of no-tillage with or without mulching were larger in dry conditions than humid conditions. Chen et al., (2007) found that straw mulching may retard seed germination and early growth of crops, especially in relatively cold climatic conditions.

Faucette et al. (2004) defined mulch as a layer of decaying organic matter rich in nutrients, moisture absorbent on the ground. Mulch comes in two basic forms, organic and non-organic. The most frequent items used in organic mulching are grass (hay, bark, compost, leaves, straw, etc.), straw and bark. While the most frequently used items in non- organic mulching are stones, small chips of brick and even plastic. Soil mulching (with plastic or straw) reduces evaporation, modifies soil temperature and thereby affects crop yields. Reported effects of mulching are sometimes contradictory, likely due to differences in climatic conditions, soil characteristics, crop species, and water and nitrogen (N) input levels (Qin et al., 2015). Mulching improves nutrient and water retention in the soil by reducing soil evaporation and preventing soil erosion by water and wind. It also encourages favourable soil microbial activity through the action of termites. The mulch decomposes and is gradually incorporated into the soil fertilizing it and improving soil structure in the long term. When properly executed, mulching can significantly improve the well-being of plants and reduce maintenance as compared to bare soil as it suppresses weed growth (Eid et al., 2016). Existence of mulch on the soil surface also affects soil temperature, which in turn influences crop growth, especially of winter crops (Chen et al., 2007).

A previous study (Qin et al., 2015) analysing the effects of mulching on wheat and maize concluded that mulching significantly increased maize and wheat yields, water and nitrogen use efficiency by up to 60%, compared with no-mulching (Fig 2.2). As such, mulching could contribute to narrowing the yield gap between attainable and actual yields, especially in dryland and low input agriculture. However, effects were larger for maize than wheat, and larger for plastic mulching than straw mulching. Interestingly, plastic mulching performed better at relatively low temperature while straw mulching showed the opposite trend. The conclusion was, as a potential climate change adaptation, mulch has a positive effect on yield and therefore contributes to improving household food security and mitigates the effects of climate change and increase rainfall variability.

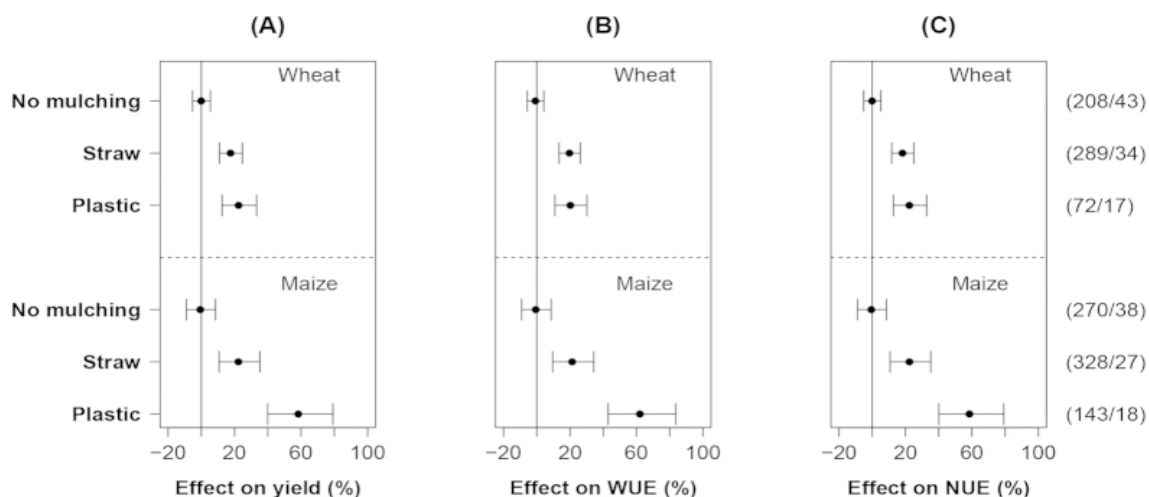


Figure 2.2: Effect of mulching on crop yield (A), water use efficiency (B) and nitrogen use efficiency (C) of wheat and maize. Dots show means, error bars represent 95% confidence intervals (Source: Qin et al., 2015)

2.3.2 Integrated soil fertility management

With the low levels of fertiliser use and poor soil quality in SSA, fertiliser use must increase if the region is to reverse the current trends of low crop productivity and land degradation (Vanlauwe and Zingore, 2011). There are renewed efforts to increase fertiliser use in SSA through increasing fertiliser availability at prices affordable to smallholder farmers. Since fertiliser is very expensive for most smallholder farmers in SSA, integrated soil fertility management (ISFM) has been proposed as an alternative framework for boosting crop productivity through combining fertiliser use with other soil fertility management practices, adapted to local conditions (Place et al., 2003; Bhuchar et al., 2004).

Integrated soil fertility management is a set of agricultural soil fertility management practices adapted integrated with local knowledge conditions to maximize the efficiency of soil nutrients and crop water use to improve agricultural productivity using fertiliser, organic inputs and improved varieties (Vanlauwe and Zingore, 2011). Integrated soil fertility management is becoming more accepted by development and extension programs, especially by smallholder farmers in SSA. The use of organic mulches could also contribute to ISFM practices and contribute to improving soil structure and fertility in rural areas.

2.3.3 Crop diversification – soybean

Soybean (*Glycine max*) is an important legume crop with clear attributes that could positively contribute to soil fertility, human nutrition, household income and poverty reductions, which are contributions that are mostly needed in SSA smallholder farming systems (Chianu, 2006). Soybean is a valued crop due to its multiple uses as a source of livestock and aquaculture feed, protein and oil for the human diet and biofuel. Despite growing productivity in many parts of the world, the average crop yields in SSA have stagnated at less than 30% of regional potential (Hartman et al., 2011). The low yields in SSA have been attributed to several reasons, key among them being poor soils aggravated by low fertiliser use, poorly developed agricultural advisory services and farmer's inability to access favourable inputs and markets.

Soybean as a leguminous crop, fixes nitrogen and has a low carbon foot print compared to cereals. With actual yields estimated at less than 30% of potential yields and only about 7% of favourable land allocated to soybeans, SSA presents a great opportunity for closing this global demand-supply gap (Mutegi et al., 2008; Hartman et al., 2011). Low soybean yields in SSA are attributed to the use of low yielding varieties, limited application of fertilisers and limited utilization of rhizobia inoculants in soils with no history of soybean production (Woomer et al., 2012).

2.4 Climate Smart Agriculture

Climate-smart agriculture (CSA) is agriculture that sustainably increases productivity, whilst adapting to and mitigating climate change (Food and Agriculture Organisation of the United Nations, 2010). According to Grainger-Jones (2009a) climate smart agriculture integrates the three dimensions of sustainable development namely economic, social and environmental by jointly addressing food security and climate change challenges and composing of three main pillars, which are:

- i. sustainably increasing agricultural/farm productivity and incomes,
- ii. strengthening resilience to climate change and variability, and
- iii. mitigating the contribution of agricultural practices to climate change through a reduction and removal of greenhouse gas emissions, where possible.

There is a growing consensus that climate change is transforming the context for rural development, changing physical and socio-economic landscapes and making smallholder development more expensive. On the other hand, there is less consensus on how smallholder

agriculture practices should change as a result (Meybeck et al., 2012). There is growing acknowledgement that agricultural and food production systems need to change, irrespective of climate change. Smallholder agricultural systems in developing countries need to undergo transformation not only for food security but for poverty reduction, aggregate growth and climate change (Parry et al., 2007). The efficiency, resilience, adaptive capacity and mitigation potential of the production system can be improved by improving production components. Campbell et al. (2014) proposed to use CSA principles to build resilience to climate change and variability, and improving crop and water productivity for smallholder farming systems.

Climate smart agriculture also includes several conservation agriculture practices such as (i) minimal mechanical soil disturbance such as no tillage or direct seeding, (ii) use of a mulching material rich in carbon organic matter and feeds the soil and (iii) crop rotations with nitrogen fixing legumes (Lipper, 2010; Campbell et al., 2014). Using methods and practices that increases organic nutrient inputs, retention and use are therefore fundamental and reduces the need of synthetic fertilisers which, due to cost and access, are often unavailable to smallholders. Maintenance of a mulch layer provides a substrate for soil-inhabiting microorganisms which helps to improve and maintain soil water and nutrients in the soil.

2.5 Conclusion

The effects associated with climate change and variability pose significant challenges to regions that depend on agriculture for survival and livelihood. Current evidence shows that climate change is occurring and developing countries are most vulnerable to the effects whilst Sub-Saharan Africa's rural economy remains strongly based on agriculture relative to other regions. The impacts of climate change will have significant major effects on agricultural food production, and thus global food security, with a decrease of production in certain regions and increased variability of production to the extent that important changes need to be made in the regions where crops are cultivated. Research and policies should aim to provide guidance to smallholder farmers, promote the use of adaptation strategies and improved inputs. Although knowledge of how best to do adaptation is still in its infancy, the Parties of the UNFCCC are increasing their support for action on adaptation. This includes the development of national adaptation programmes by some developing countries including least developed countries, and their integration into national strategies. Climate change solutions need to identify and exploit synergy.

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CHAPTER 3

MATERIALS AND METHODS

3.1 Plant Material

Soybean seed variety LS6161R was donated by Link Seeds during October 2015. This variety is a roundup ready with semi-determinate growth type and narrow-leaved that is well adapted to both dryland and irrigated growing conditions. Under good favourable conditions, the variety reaches 50% flowering in 60 to 68 days, and takes 140 to 150 days to reach harvest maturity with plant height varying between 95 and 105 cm.

3.2 Study Site Description

The study was conducted over one growing season (2015/2016) at Swayimane High School, Wartburg (29°31'08.02''S; 30°41'35.59''E; 883 m a.s.l) in KwaZulu-Natal South Africa. Bezuidenhout and Singels, (2007) classified this area as a semi-arid environment receiving a mean annual rainfall of about 732 mm, with 80% of rainfall occurring mainly between November and April. The area receives the lowest rainfall of 5 mm in June and the highest rainfall of 116 mm in January. Wartburg has average midday temperatures for the area range between 19.7°C in winter to 26.2°C in summer.

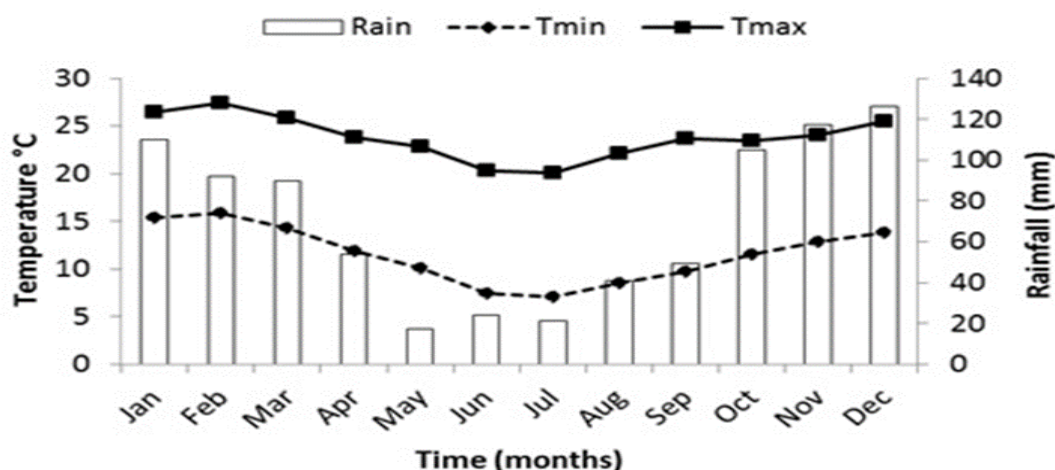


Figure 3.1: Average monthly temperatures (maximum and minimum) and rainfall distribution for Swayimane over a period of ten years (Bezuidenhout and Singels, 2007).

3.3 Soil and soil water content

Soil samples were obtained at 0.15 m for soil nutrient analysis before planting. Soil field capacity and permanent wilting point were determined for three soil depths (0.15 m, 0.3 m and 0.6 m). Soil water mark sensors model A200SS-5, irrometer, Riverside CA, USA were inserted at different depths (0.15, 0.3, 0.6 m) to measure the soil electric resistance (kPa) that results from the presence of water in the soil and recorded on a data logger (CR1000 Campbell Scientific Africa, Somerset West, RSA) located between blocks in the field. The resistance measured then was used to get a gravimetric soil water curve graph and the equation derived from each depth was used to convert the soil water resistance to volumetric soil water content.

3.4 Experimental Design

The field trial was a split plot design with sub-plots laid out in a randomized complete block, replicated three times. The main plots were two levels of mulch treatment, no mulching (NM) and mulching (HM) using grass bale (15-25% moisture content) bale at the rate of 40 tonnes/ha. Sub plots were three phosphorus (P) and potassium (K) fertiliser levels (0%, 50% and 100%). An 18m × 9m main-plot was used (mulch) and a 6m × 3m sub-plot area was used (fertilised) resulting in 9 sub-plots of either mulched or NM main-plot. Each sub-plot had a spacing of 0.5m between rows and a spacing of 0.05m between plants, 7 rows, with the expected plant population to be 120 plants per row making 720 plants per sub-plot and 12960 plant population in total i.e. 80000 plants per ha. The hay mulch was applied after soybean had fully established and formed two leaves. The rate at which the mulch was applied was at 40 tonnes per hectare.

3.5 Agronomic Practices

Soybean was sown on 6 November 2015, and harvested in March 2016. Prior to planting the, land was prepared and a pre-planting herbicide was applied 7 days before planting to control narrow leafed grass. Due to the seed size and the spacing used the soybean seeds were broadcasted within a row. After plant establishment the rows were thinned to 5 cm spacing within plants and gap filling was done from the rows that had high emergence to account for seedlings that did not emerge. The land preparation and weeding were done by hoeing and hand pulling of weeds. Based on soil fertility results single supers: P (10.5%) and KCl (0-0-60) were used. For the fertiliser that were recommended 100% was the recommendation, 50% was half the recommendation and 0% was not applying fertiliser. Fertiliser was then broadcasted after planting.

3.6 Data Collection

3.6.1 Weather Data

An automatic weather station (AWS) was installed at the field, 1 m away from the trial and 2 m above the ground (Figure 3.2). Temperature (minimum, maximum), daily rainfall and daily evapotranspiration (ET_o) were measured.



Figure 3.2: Automatic weather station at the trial site.

3.6.2 Field Data Collection

Data on crop growth parameters were collected to evaluate the performance of soybean (*Glycine max*) in response to straw mulch and three fertiliser levels. Data collected during the study included observed plant emergence, and counted plants that had emerged from each row from one week after planting until 90% emergence was counted. Visual counting of total number of fully unfolded expanded leaves half or more of the leaf should be green. Trifoliate leaf will be considered as one leaf. In soybean, the first leaves to develop after emergence are the unifoliate leaves, two of these single leaves appear directly opposite one another above the cotyledons and then all other subsequent leaves are trifoliate comprised of three leaflets and are considered as one leaf. Plant height measured from the base of the plant to the apical/apex meristem of the upper most leaf of the plant until the plant has reached maturity. Leaf area index (LAI) was measured using the LAI-2200C Plant Canopy Analyser (Decagon Devices, Inc., USA) which uses a non-destructive method. The measurements were taken every two weeks after crop establishment until harvest. Stomatal conductance steady state was determined using the Model SC-1 Leaf Porometer (Decagon Devices, Inc., USA) which determines stomatal conductance by measuring the actual vapour flux from the leaf through the stomata from the abaxial surface of the leaves. Chlorophyll content index the SPAD-502Plus Chlorophyll Meter (Konica Minolta, USA) was used; it instantly measures plant chlorophyll content on a scale of -9.9 to 199.9 from a leaf adaxial surface. Soil water sensors were inserted on the field at different depth of 0.15 m, 0.3 m, 0.6 m and at 1 m around the plants for soil water content. Thermocouples were inserted to the rooting zone of the plant for soil temperature.

3.6.3 Harvest Data Collection

A 1 x 1 m quadrant square metre was used to harvest plants from each plot at harvest maturity. Number of plants within a square meter were counted, weighed for biomass per square meter, pod number, pod mass, seed number and seed mass. Post-harvest standard germination, grain moisture and seed water activity tests were done.

3.7 Seed Quality

3.7.1 Standard Germination Test

Pre-planting standard germination counts were taken at 24 hour intervals. A seed was considered to have germinated when a 2 mm radicle protrusion was observed. On the last day root length (cm); shoot length (cm); fresh mass (g); dry mass (g) and root: shoot ratio measurements were taken. Germination percentage, mean germination time (MGT),

germination index (GI) and time to 50% germination (T50) were then calculated using the following equations:

The germination percentage (GP) was calculated:

$$\text{Germination percentage} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds incubated}} \times 100 \quad \text{Equation 3.1}$$

The germination index (GI) and time to 50% germination (T50) were calculated according to the formulae used by (Zanjan and Asli, 2012):

$$\text{Germination index (GI)} = \frac{\sum TiNi}{S} \quad \text{Equation 3.2}$$

The mean germination time (MGT) was calculated by using the formula:

$$\text{MGT} = \frac{\sum (n \times d)}{N} \quad \text{Equation 3.3}$$

where, n = number of seeds germinated on each day, d = number of days from the beginning of test, and N = the total number of seeds germinated at the termination of the experiment.

3.7.2 Seed Water Activity (*a*W) and grain Moisture Content %

Six replications were used to determine harvested seed water activity using Decagon Model Aqua Lab Series 3 meter (US) and moisture content using Model am-5000 (China)

3.8 Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) using GenStat® (Version 18, VSN International, UK). Differences between means were compared by Duncan analysis ($p \leq 0.05$) level of significance.

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CHAPTER 4

THE EFFECTS OF MULCH AND FERTILISER USE ON GROWTH, PHYSIOLOGY AND YIELD OF SOYBEAN

4.1 Introduction

Soybean is a dual-purpose crop as it is an important food crop for food and nutrition security and has since gained popularity as biofuels crop (Hartman et al., 2011). There is debate on whether soybean should be used to produce biofuels. On one side, it is believed that soybean can help ease of the double burden of food and nutrition insecurity that is characterised by majority of poor South Africans who reside in rural communities. On the other hand, South Africa is committed to the reduction in use of fossil fuels and increase the production and use of biofuels. It is suggested that allowing smallholder farmers to participate in production of soybean can address both issues by increase household access to soybean as a food crop while the excess can be sold towards the manufacture of biofuels (FAO, 2009; Searchinger et al., 2013). This will directly improve rural development and general livelihoods. However, productivity levels in smallholder agriculture systems are generally low and this has been attributed to highly degraded soils and coupled with low and variable rainfall (IFAD, 2013; Thierfelder et al., 2015). Furthermore, the impacts of climate change and variability has increased the incidence and severity of droughts and has resulted in the delayed onset of season rainfall (Brown et al., 2012; Chinsinga et al., 2012). There is need to come up with strategies that can sustainably promote the production of soybean while at the same time ensuring high yields are obtained. Furthermore, such strategies should not be detrimental to the environment, but improving it.

To improve agricultural productivity under rain-fed conditions, the introduction of climate smart agriculture strategies in smallholder communities is a sustainable solution that has been shown to address issues of productivity and mitigation (Edame et al., 2011; Harvey et al., 2014). Climate smart agriculture are any agricultural techniques that increase productivity in an ecologically sustainable manner while at the same time mitigating against climate change (see Section 2.4). Within this context, the introduction of soybean, coupled with soil-water conserving strategies can be administered as a CSA technology. Under such approaches mulching, appropriate fertiliser use and adoption of alternative crop choices are approaches

promoted on smallholder farms to improve agricultural productivity within rain-fed farming systems (Alliance for a Green Revolution in Africa (AGRA), 2014).

Mulch is a layer of material applied to the surface of an area of soil to conserve moisture to improve the fertility and health of the soil, to reduce weed growth to enhance the visual appeal of the area (Grampp, 2015). Mulching strategy reduces soil temperature resulting in a reduction in bare soil evaporation, this improves the availability of soil water for crop transpiration, and subsequent growth and yield (Qin et al., 2015). The use of appropriate fertilizer rates has been observed to significantly increase crop yields. A complete and balanced fertility program will produce vigorous and increased root growth such that more soil volume for water is explored in less time. This results in a healthier crop that can more easily withstand water limited conditions (Place et al., 2003). Overall, the combined approach of mulching, appropriate fertiliser and use of alternative crops could be used to improve agricultural productivity. To test this hypothesis, the objective of the study was to access the impacts of mulch and fertiliser on growth and productivity of soybean.

4.2 Results

4.2.1 Weather observed

The average maximum and minimum temperature were 25.8°C and 16.08°C respectively. The temperature range was 38.8°C to 9.97°C. The results show that, for 29 days soybean experienced intermediate stress due to exposure to high threshold temperature above 30°C that inhibit growth (Dlamini et al., 2013). During the growing period, soybean received a total of 480.58 mm of rainfall. Rainfall distribution was somewhat uneven during the growth periods. It was observed that most of the rain (183.01 mm) was received during periods starting from grain filling while emergence and vegetative, flowering, pod formation stage each received 70.71, 68.59, 59.64, 64.60 and 52.67 mm respectively. Between reproductive and senescence, more rainfall was received than in any other growth stage, and it amounted to 130.34 mm. Reference evapotranspiration was a total of 334 mm and it was less than the rainfall received of which it was 480.58 mm.

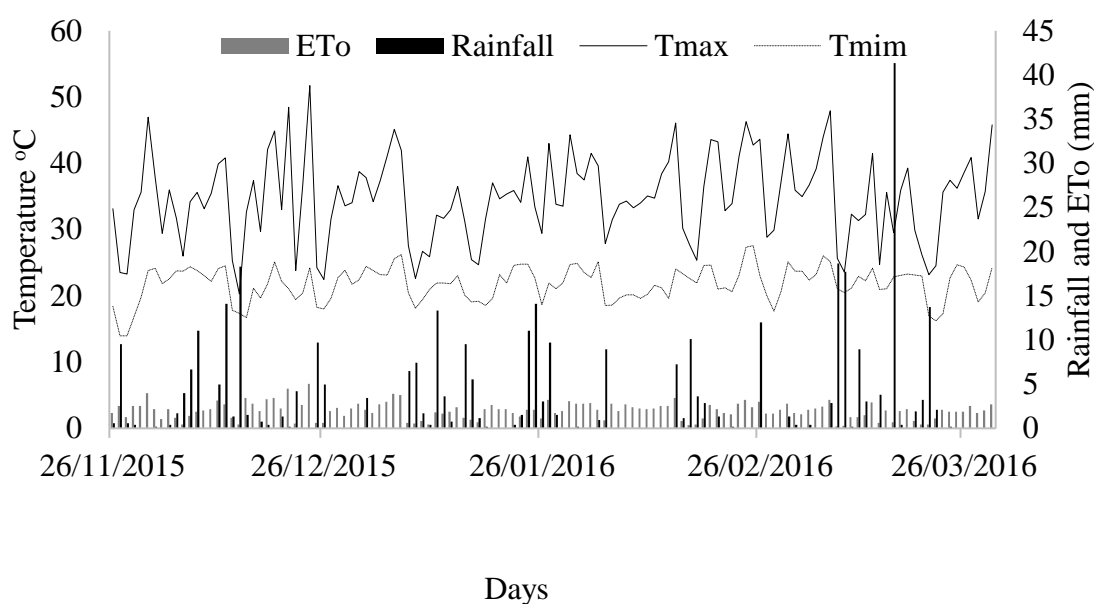


Figure 4.1: Climatic weather showing rainfall (mm), ETo (mm), minimum and maximum temperature (°C).

4.2.2 Effect of mulching and fertiliser on soil water content

The observed soil water content (SWC) results for the study show that there was an even distribution of water throughout the field with the highest soil water content (SWC) amount observed at deepest soil depth used (60 cm) for both hay-mulch and non-mulch. Overall, hay-mulch had higher soil water content (SWC) relative to non-mulch (38.48% > 32.95%) (Figure 4.2 and 4.3). It was observed that SWC was observed to increase with each rainfall event. Soybean grown under hay-mulch treatment, the trend for SWC across the fertilizer treatment

100% (39.47%) > 0% (38.57%) > 50% (37.87%). It was observed that SWC was observed to increase with each rainfall event. For soybean grown under non-mulch treatment, the trend for SWC across the fertilizer treatment 0% (34.45%) > 100% (33.74) > 50% (30.66%). The SWC at 15 cm fluctuated in-between field capacity and permanent wilting point. On the other hand, at 30 cm SWC was at and above field capacity while at 60 cm SWC was above the field capacity.

4.2.3 Effect of mulching and fertiliser on crop physiology

4.2.3.1 Effect of mulching and fertiliser on chlorophyll content index (CCI)

There were significant differences ($P=0.010$) observed for the CCI of soybean under hay-mulch and non-mulch (Figure 4.4). Hay-mulch and non-mulch had an average CCI of 46 and 39 respectively. At 5 WAP, hay-mulch had the highest CCI of 52 and by the end of the season it was observed that it had a highest decrease of 25%. On the other hand, at 5 WAP non-mulch had the lowest CCI of 40 and by the end of the sampling period it was observed that it had also a lowest decrease in CCI of 6 of which it was not an acute decrease as in the case of hay-mulch.

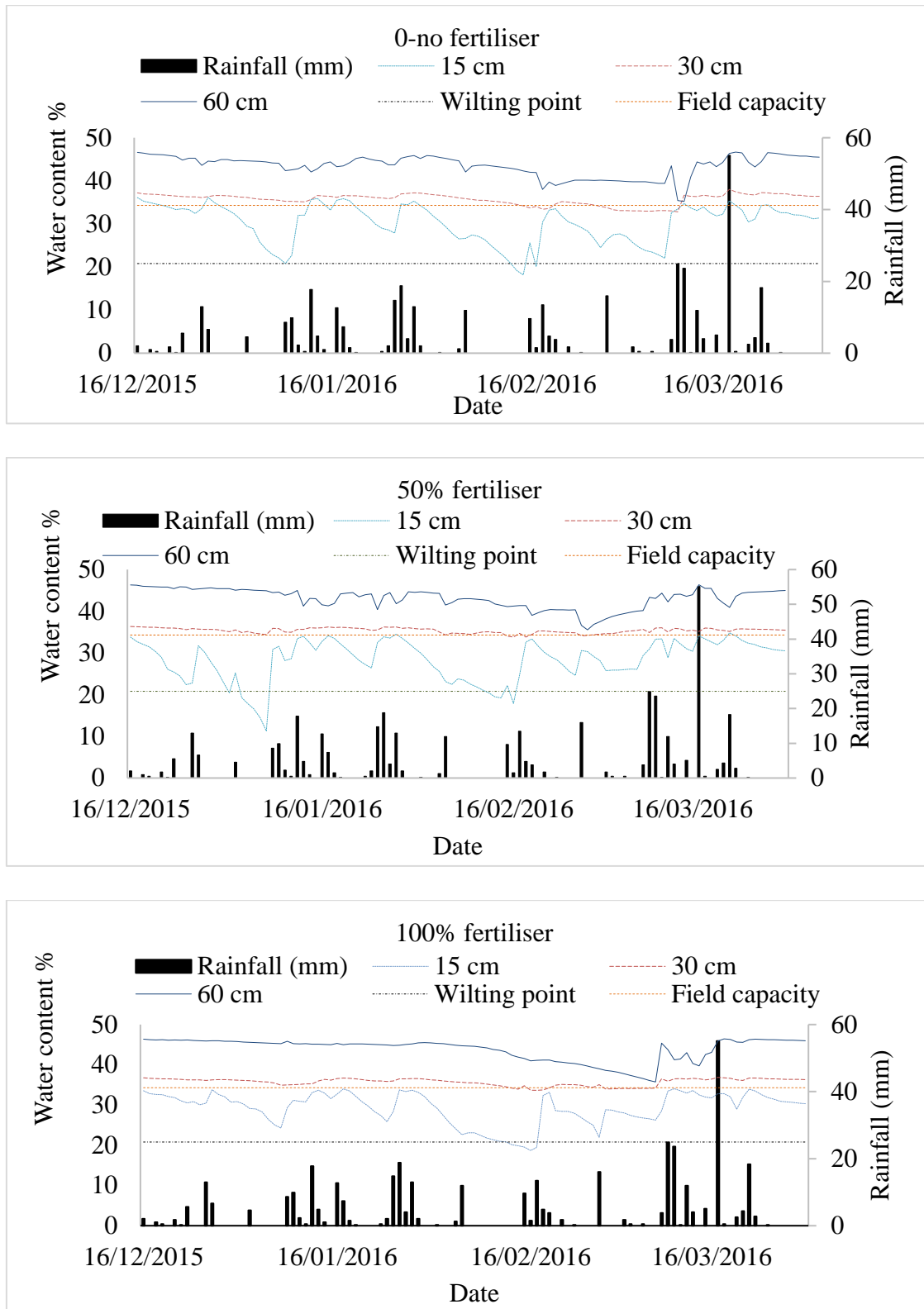


Figure 4.2: A comparison of volumetric soil water content (SWC) % for different depths (15, 30 and 60 cm) over the growing period for soybean grown with hay-mulch across different fertiliser regimes (0, 50 and 100% recommended fertiliser application rates).

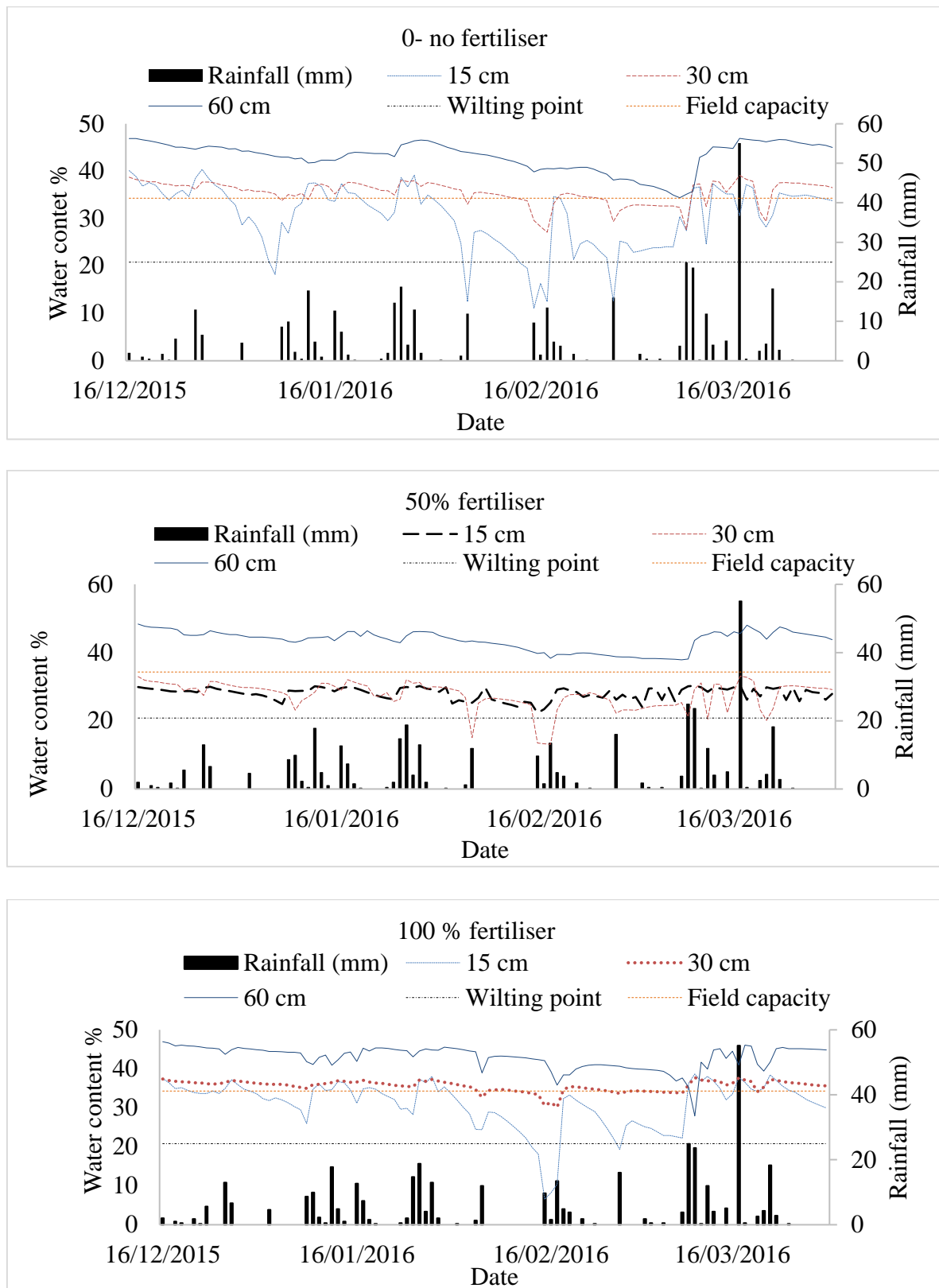


Figure 4.3: A comparison of volumetric soil water content (SWC) % for different depths (15, 30 and 60 cm) over the growing period for soybean grown with no-mulch across different fertiliser regimes (0, 50 and 100% recommended fertiliser application rates).

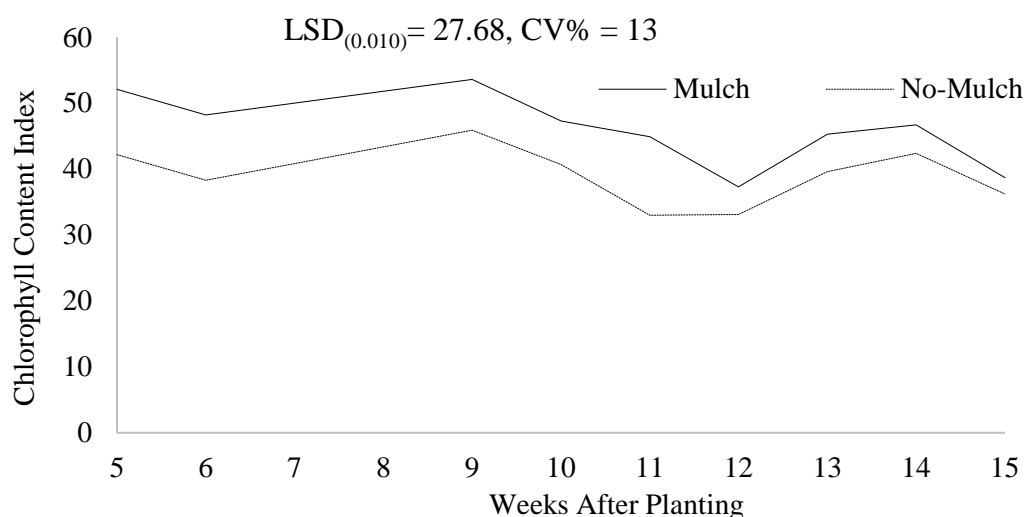


Figure 4.4: The comparison of soybean chlorophyll content index in response to mulching treatments (hay-mulch and non-mulch) over time.

4.2.3.2 Effect of mulching and fertiliser on stomatal conductance

There were no significant differences ($P = 0.057$) observed for the stomatal conductance of soybean under hay-mulch and non-mulch (Figure 4.5). What was interesting to note was the response of soybean stomatal conductance over time. Stomatal conductance was somewhat consistent over time with an exception of 9 WAP. It was observed that the stomatal conductance was observed to be drop significantly at 9 WAP (flowering stage) to $99 \text{ mmol m}^{-2} \text{ s}^{-1}$. This sudden drop was attributed to weather conditions. On this day the conditions were overcast with high relative humidity, low temperature and moderate rainfall (Figure 4.1).

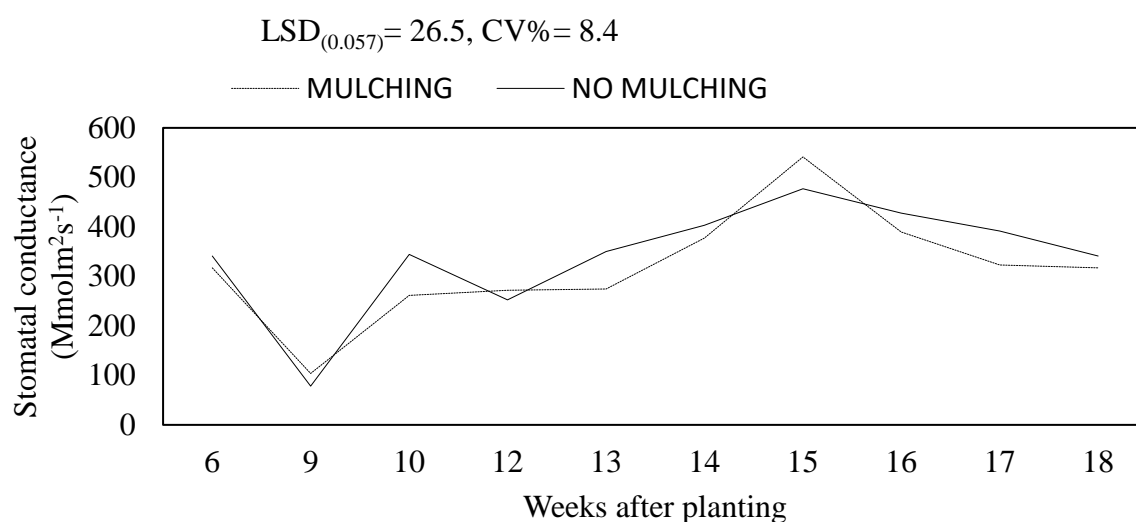


Figure 4.5: The comparison of soybean stomatal conductance ($\text{Mmol m}^{-2} \text{s}^{-1}$) in response to mulching treatments (hay-mulch and non-mulch) over time.

4.2.4 Effect of mulching and fertiliser on crop growth

Plant height and leaf area index for soybean showed no significant responses with regards to the interaction of mulching and fertilizer ($P > 0.05$) for both parameters. The same average was observed for plant height (41.5 cm). However, leaf number for soybean observed was significantly different ($P = 0.039$) when grown under different mulch treatments over time (Figure 4.6). Overall, non-mulch had higher (11) leaf number in comparison to hay mulch (9). Under non-mulch, a gradual increase in the number of leaves was observed at 5 weeks after planting WAP (vegetative stage) until 12 WAP (grain filling stage), then again a sharp decrease in the number of leaves occurred until maturity 15 WAP. Contrary, to what was observed under no mulch, for soybean grown with hay-mulch, a sharp increase in the number of leaves was observed from 5 WAP to 9 WAP, and then had a sharp decline in the number of leaves was observed at 10 WAP which was the flowering stage. The sudden reduction in leaf number observed when soybean was grown with mulch was attributed to observed fungal disease that could have transferred from the hay mulch used.

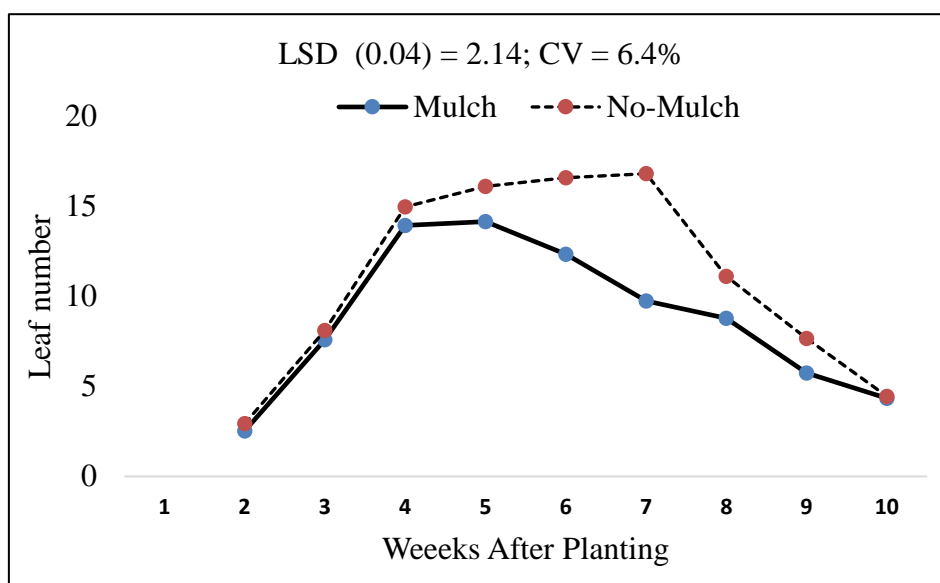


Figure 4.6: The comparison of soybean leaf number in response to mulching treatments (hay-mulch and non-mulch) over time.

4.2.5 Effect of mulch and fertilizer on soybean yield

There were no significant statistical differences ($P > 0.05$) observed with respect to harvest parameters (Table 4.1).

Table 4.1: Soybean yield parameters showing the effect of mulch and fertilizer.

Mulching	Fertiliser level (%)	Plant number/ m²	Total biomass /m² (g)	Pod mass/ m² (g)	Pod number/ m²	Seed mass/ m² (g)	Seed number/ m²
Mulch	0	48ac	113.4a	56.2a	222a	22.1a	251a
	50	28.7abc	110.5a	64.3a	219a	31.7ab	305abc
	100	24a	128.4a	62.6a	251a	28.2a	251a
Mean		33.7	117.4	61.0	231	27.4	269
No-Mulch	0	28.7abc	106.4a	58.7a	219a	23.1ab	274ab
	50	24.7ab	165.0a	90.4a	310a	39.6ab	470ac
	100	34abc	142.5	61.9a	235a	25.5ab	308abc
Mean		29.1	138.0	70.4	255	29.4	351
P (0.05)		NS	NS	NS	NS	NS	NS
LSD (0.05)		18.19	47.1	25.58	102	11.7	131.4
CV%		11.2	18.2	16.8	19.8	17.7	19.0

*NS-Not significant at 5% level of significance.

4.3 Discussion

Soybean is very sensitive to environmental conditions, the main climatic factors affecting its crop yields include the photoperiod which influences the availability of full light, temperature and water availability (Mundstock and Thomas, 2005). For the current study, it was observed that water availability is a critical factor for sustaining crop productivity under rain-fed agriculture as also observed by (Harvest Choice, 2010). Hay-mulch was observed to improve water availability as it had higher SWC when compare to non-mulch. Mulch reduces water loss by minimising soil evaporation and off-field runoff resulting in more water being made available in the soil for crop use. The observed fluctuations of SWC in the 15cm soil depth suggest that there was higher root water uptake and the most soil evaporation occurrence than in the bottom layers 30 and 60 cm. At this depth and across the season, the observed reduction of SWC below permanent wilting point (PWP) was more frequent under non-mulch than hay-mulch suggesting that mulch could have reduced the contribution of soil water lost through

evaporation. This would also suggest that soybean grown under non-mulch could have experienced incidences intermediate stress during the growing season. Evaporation from the soil surface significantly affects crop water use efficiency. Mulching increases water availability and prevents soil evaporation (Chen et al., 2007; Grainger-Jones, 2009b). Chakraborty et al. (2008) concluded that under limited water condition, mulching will be beneficial as it can maintain better soil water status. As much as the effect of various environmental factors that interfere with the performance of crops exists, water restriction is the main limiting factor that contributes to the failure to obtain maximum soybean yields and influencing the use of other environmental resources (Bhatia et al., 2008; Casagrande et al., 2009).

Smallholder farmers located in low rainfall areas, mulch should be considered as a water management strategy to improve soil water content. Shongwe et al. (2014) reported that rainfall frequency, distribution and intensity have changed. Rainfall is poorly distributed throughout the growing season, such that there is often no rain during the maturity stage of most crops. This results in crop failure even if the crop has been performing well during the early stages of development. Similarly, long dry periods have been observed during the planting season because of changing rainfall patterns which affect plant growth and eventually crop yield. Symbiotic nitrogen fixation is one of the most important processes of nitrogen nutrition of soybean, which results in improvements of productivity and profitability of the crop. This process is negatively influenced by low soil moisture content as (Purcell and Specht, 2004) reported. On another study, Purcell et al., (2000) concluded that water shortfall promotes the accumulation of products of N_2 fixation (ureides) in the shoot of soybean plant, causing a feedback reduction in fixation of N_2 . Thus, most proper soil nutrients with manganese (Mn^{+2}) promotes the breaking of ureides and extends N_2 fixation in plants under water deficit.

Observing the results on rainfall and reference evapotranspiration (ET_o) for the study period, the results showed that the ET_o of the environment soybean was grown in was less than the rainfall received, indicating the atmospheric conditions having a limitation on the carbon exchange, photosynthesis and transpiration of soybean. The variability of the rainfall had a late onset of rains for the first half of the growth period (October, November and December). Of which the first three months of the season are the most important for seed germination and favour the crop at early vegetative stages. Adequate rainfall was received towards the end of the growth season when soybean had grown past the reproductive stages. Hence, different crop growth stages have different sensitivity levels of development to water stress, low water availability to water during critical stage can have a higher impact on yield than other stages

(Harvest Choice, 2010). In many crop species, the effects of high temperature stress are more damaging on reproductive development than on vegetative growth and the sudden decline in yield with temperature is mainly associated with pollen retardation. The susceptibility to high temperatures in plants varies with the stage of plant development, heat stress affecting to a certain extent all vegetative and reproductive stages (Semenov and Shewry, 2011; Bitu and Gerats, 2013). Temperature plays an important role in determining the rate at which soybeans grows. The optimum air temperature for photosynthesis in soybean is 25-30°C and the carbon dioxide assimilation by soybean is reduced by 20% when the leaf canopy temperature is increase from 30-40°C. Adversely affected as temperatures rise above 30°C, while temperatures below 13°C for long periods during flowering stage inhibits flower and seed formation. For the current study, higher than average temperatures optimum for soybean growth were observed (9-38°C). Hence from the observed information, soybean experienced more days under threshold temperatures limiting its growth. Fluctuations in temperature occur naturally during plant growth and reproduction. However, extreme variations during hot summers can damage the intermolecular interactions needed for proper growth, thus impairing plant development and fruit set (Bhatia et al., 2008).

The effect of rainfall and high temperatures observed better explain the soybean growth and phenological performance observed. According to Lisar et al., (2012) under water stress conditions plants present a series of changes in their morphology, physiology and biochemistry which negatively affect their growth and productivity. As the observed results for chlorophyll content index for soybean showed that mulching can improve CCI. This was attribute to the improvement of total available soil water content relative to non-mulched soybean. Chlorophyll content in plants is degraded under water limiting conditions. Chlorophyll content index can be correlated to the amount of active chlorophyll in a leaf (Khayatnezhad and Gholamin, 2012). Under water stress conditions, chlorophyll content degrade as a stress coupling mechanism thus less photosynthesis occurs. The damage on photosynthesis II under water stress often results in an increase in free electrons that tend to bid with other molecules often forming reactive oxygen species (ROS) that are detrimental to plant cell organelles. The observed low CCI under non-mulched conditions could be an adaptive response to the low water availability minimise the production of ROS and maintain cellular integrity relative to hay mulched. Therefore, growing soybean under hay-mulch can help maintain chlorophyll integrity which can result in improve photosynthesis. Water requirement for soybean increases with plant development, having an increased requirement during flowering to grain filling stages and decreasing thereafter of about 7-8 mm per day of which its less than what was received or available for the study daily during

reproductive stage. The total water requirement for maximum yield is reported to be 450 mm 800 mm of which for the season period it is much more than what was received from rainfall.

Hay-mulch was expected to affect soybean growth and retain SWC as it has done in other studies. However, it was observed that hay-mulch had an effect in SWC only. The observed number of leaves for soybean show that non-mulch had more leaves than hay-mulch Figure 4.6), same increase during early-vegetative for both hay-mulch and non-mulch was observed. At mid vegetative non-mulch hay-mulch had a gradual decrease in the number of leaves from reproductive stage. On the other hand, non-mulch had a higher number of leaves. The effects of water stress at different development soybean stages is associated with the stress induced at flowering stage of soybean. The observed results on the yield parameter of soybean are not significant for any of the treatments. The number of pods per unit of shoot dry matter was significantly affected by water deficits in the reproductive stages (grain filling). When stress occurred during grain filling, the characteristics of the plant that were most affected were the number of grains per pod and the grain weight.

Soybean grown under hay-mulch had high total available water than non-mulch suggesting that growth and yield should be higher than what was observed. It could be that the no significance observed in this study could be due to other factors such as soil pH. A closer look at the soil fertility analysis showed that soil pH was low (4.2). Soybean would generally perform well in soils with pH 6 to 7 with an optimum soil pH of 6.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, plus this range of pH is generally very compatible to plant root growth. Potassium (K) is one of the major plant nutrients that appear to be less affected directly by soil pH than many others (Casagrande et al., 2009). However, phosphorus (P), is directly affected by soil pH. At pH values, greater than pH 7.5 (alkaline) phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds. At pH values, less than 5 (acidic), phosphate ions react with aluminium (Al) and iron (Fe) to again form less soluble compounds (Jensen, 2010). When soil pH drops, aluminium (Al^{+}) becomes soluble. A small drop in pH can result in a large increase in soluble aluminium. In this form, aluminium retards root growth, restricting access to water and nutrients (Chianu, 2006; Vanlauwe and Zingore, 2011). Hence poor crop growth, yield reduction and smaller grain size occur because of inadequate water and nutrition. Water stress during vegetative or early reproductive growth usually reduces yield by reducing the number of seeds in crops. while water stress during seed filling reduces seed size (Rusinamhodzi et al., 2012), and yield can be reduced by short periods of stress during flowering and pod filling in

soybean. Water stress during seed production of soybean usually reduced seed yield as observed.

4.4 Conclusions

The objective of the study was to determine the effect of mulching and fertiliser use on growth and yield of soybean under rain-fed conditions. Hay-mulch was able to reduce soil evapotranspiration and retain soil water content compared to non-mulched. However, none of the treatments mulch or fertilizer affected soybean growth and yield. The rainfall variability is an important characteristic of climate in sub-Saharan Africa that imposes crop reduction in rain- from significant climate change variability which has huge implications on crop yields and food security for smallholder farmers. Crop cultivation should be situated in areas with high rainfall and low rainfall variability, however smallholder farms are found in a wide range of environmental condition. Soybean does not respond to hay mulch treatment; different mulching treatments can be further researched on its effect on soybean growth. However, mulch can be used to conserve soil water in rain-fed smallholder farming systems. To improve soybean growth under water limiting conditions, the application of additional strategies is in need, such as constant development and improvement of new soil management techniques and allowing the development of root systems to increase the water intake capacity to support the development of soybean throughout the growth period. Further research is required to investigate the long-term effect of hay-mulch on soybean physiology, growth, yield and quality under rain-fed conditions at different regions.

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CHAPTER 5

THE EFFECTS OF MULCH AND FERTILISER USE ON SEED QUALITY OF SOYBEAN

5.1 Introduction

Smallholder agricultural systems in South Africa are categorised as being resource poor and are highly dependent on rain-fed crop production as a livelihood strategy (Fisher and Snapp, 2014). Majority of the agricultural systems are characterized by small family farms and focus is on activities that favour the stability of the farm household system. As such, smallholder farmers use family labour for production, farm manure to fertilise their fields and depend largely on retained seed from harvest from the previous season. Due to the low input production systems smallholder farmers are vulnerable to water stress, which is worsened by the impacts of climate change, resulting in low and unsustainable crop production (Moyo et al., 2012). There is need to come up with strategies that can sustainably improve productivity given the multitude of constraints in with smallholder farming is practised under. Using seed of good quality has been shown to minimise the effects of water stress and improve productivity (Wilk et al., 2013). It could be that, if smallholder farmers had better access to good quality seed it could aid in improving productivity and contribute towards improved livelihood.

Seed quality is an important factor affecting the early performance and growth of agricultural crops and this makes it advantageous for resource use and productivity (McGuire and Sperling, 2011; Zanzan and Asli, 2012). A seed of quality is one with genetic purity, physical purity. In addition, it is disease and pest free and has good physiological condition (Graham et al., 2001). High quality seed is a major factor in obtaining a good crop stand and rapid plant development even under adverse conditions although other factors such as rainfall, agronomic practices, soil fertility, and pest control are also important. According to Alemu et al. (2010) the attainment of good quality seed depends on several factors, primary among them is the conditions which it is produced. Low availability of water and nutrients during growth and development of mother-plant not only affects yield but also subsequent seed quality. Such environmental conditions are similar to what is observed for smallholder farmer systems in South Africa, who are located in agro-ecological zone with low rainfall and low soil quality. Bhatia et al. (2008) reported that water stress encountered at different growth stages in crops has different effects on the subsequent seed quality. Factors other than environment can also alter seed size and

quality, in non-stressed soybean plants, seeds located within the different canopy positions had a higher germination percentage and a greater seedling growth rate than seeds from the lower canopy (Meybeck et al., 2012). In a study by Ghassemi-Golezani et al. (2010), the conclusion drawn was that seed quality of different soybean cultivars was significantly reduced by water stress during reproductive stages, particularly during seed filling phase. Seed weight and germination rate had the most effect on seedling size of soybean. Thus, sufficient water supply and production of large and uniform seeds could be a practical way to improving seed quality

Soybean has increasable nutritional qualities but it forms a very small percentage of the average household's diet in South Africa (Dlamini et al., 2013). Soybean consumption for oil and protein is at 25% whilst 60% is for animal feed with the poultry industry being the largest consumer of soybean derived proteins in SA. Many crop varieties grown in rain-fed systems are adapted to exploit moisture stored in the root zone. Rain-fed systems can be further improved by using strategies that increase soil water storage capacity, improving water infiltration and minimizing evaporation through organic mulching. The aim of this chapter was to evaluate the soybean seed quality produced under mulch and fertiliser management.

5.2 Results

5.2.1 Initial seed quality

Standard germination test results for soybean seed lot showed no significant difference ($P=0.8$) across the four replicates (Figure 5.1). Significant differences were observed ($P < 0.001$) with respect to mean germination time and germination velocity index (Table 5.1). No significant differences ($P > 0.05$) were observed with respect to seedling length, shoot length, root length, root: shoot ratio, fresh mass and dry mass. Overall, it was concluded that the quality of planted seed was highly suitable for planting.

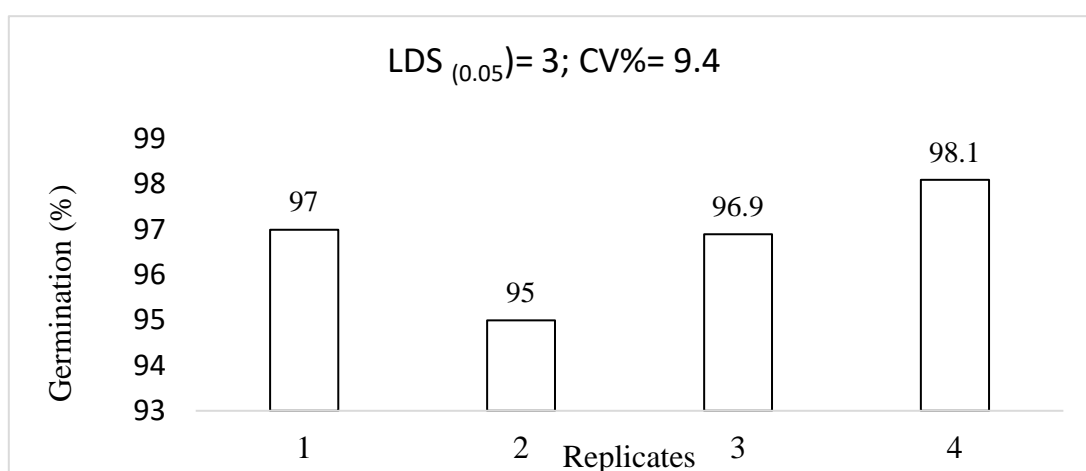


Figure 5.1: Standard germination percentage of soybean for the seed used in the study.

Table 5.1: Performance of soybean under standard germination test prior to field planting showing mean germination time (MGT), Germination Velocity Index (GVI) and seedling parameters.

	*MGT	**GVI	Seedling length (cm)	Shoot length (cm)	Root length (cm)	Root: Shoot ratio	Fresh mass (g)	Dry mass (g)
Mean	1.34	3.32	28.35	11.6	13.08	1.84	3.21	0.261
P_(0.05)	0.072	0.2	0.13	0.87	0.12	0.51	0.06	0.053
LSD	0.324	0.428	2.789	1.080	2.481	0.025	0.146	0.045
%CV	10.5	9.7	3.8	3.9	5.2	1.0	3.0	7.8

*MGT – Mean Germination Time; **GVI – Germination Velocity Index

5.2.2 Effect of mulch treatment on soybean water activity

There were significant differences ($P=0.043$) observed for soybean seeds with respect to water activity. Non-mulch resulted in higher water activity than hay-mulch with averages 0.53 and 0.49 respectively (Figure 5.2).

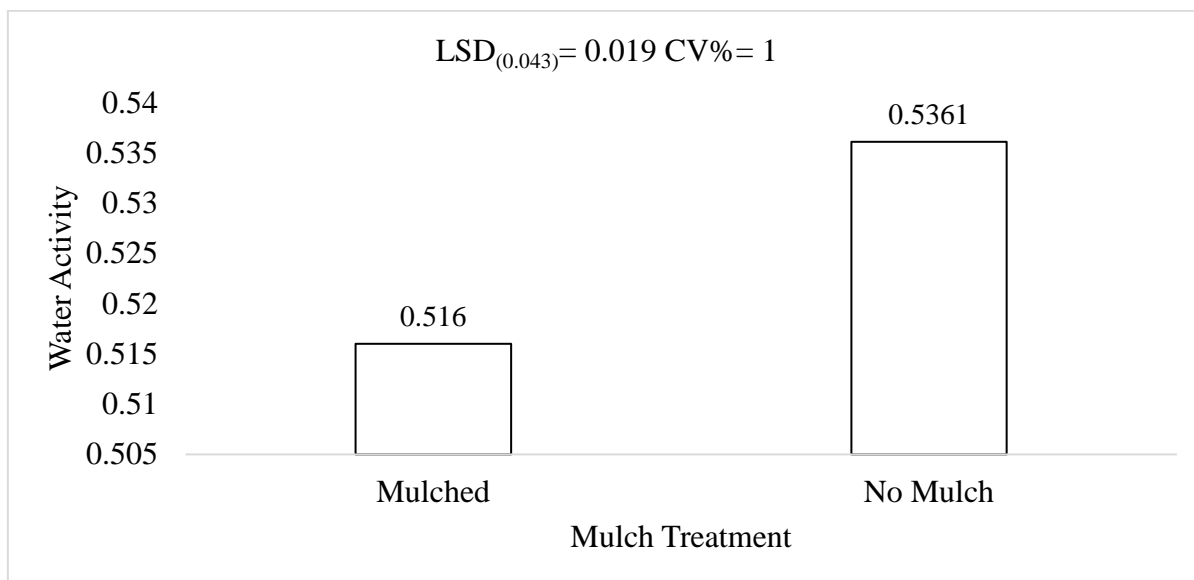


Figure 5.2: Effect of mulching treatment on soybean seed water activity.

5.2.3 Effect of mulch on soybean grain moisture %

There were no significant differences ($P>0.05$) observed for the effect of mulch treatment for soybean grain moisture (Figure 5.3). This was contrary to what was observed for water activity. Significant ($P>0.05$) differences were observed across the fertiliser rate. The trend for grain moisture was 50% (11%) > 100% (9.9) > 0% (9.6).

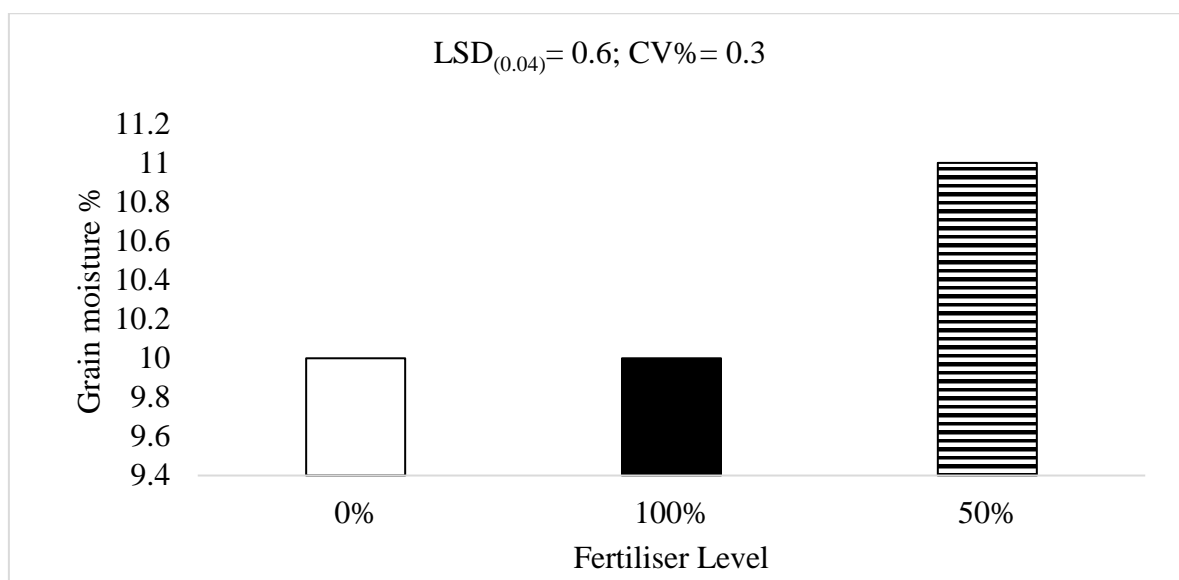


Figure 5.3: Effect of different fertiliser rates on soybean grain moisture (%).

5.2.4 Effect of mulch and fertiliser on soybean germination

There were highly significant differences ($P < 0.01$) observed with respect to the germination percentage of soybean under mulch and fertiliser treatments. Overall, hay-mulch had the highest germination of 96% than non-mulch which had 90% germination. Across the fertiliser treatments, the trend for germination percentage under mulch treatment was 50% (96.14%) > 0% (95.81%) > 100% (95%) and for non-mulch it was 100 % (93%) > 0% (89.69%) and 50% (87.04%). Furthermore, the original seed lot had higher germination percentage of 97% (Figure 5.1) but not significantly different when compared to the germination test of the subsequent seeds harvested.

Overall, there were highly significant differences ($P < 0.001$) observed with respect to mulch treatment mean germination time (MGT), germination velocity index (GVI) and root: shoot ratio (Table 5.2). There were no significant differences ($P > 0.05$) observed with respect to seedling length, shoot length, root length, fresh mass and dry mass.

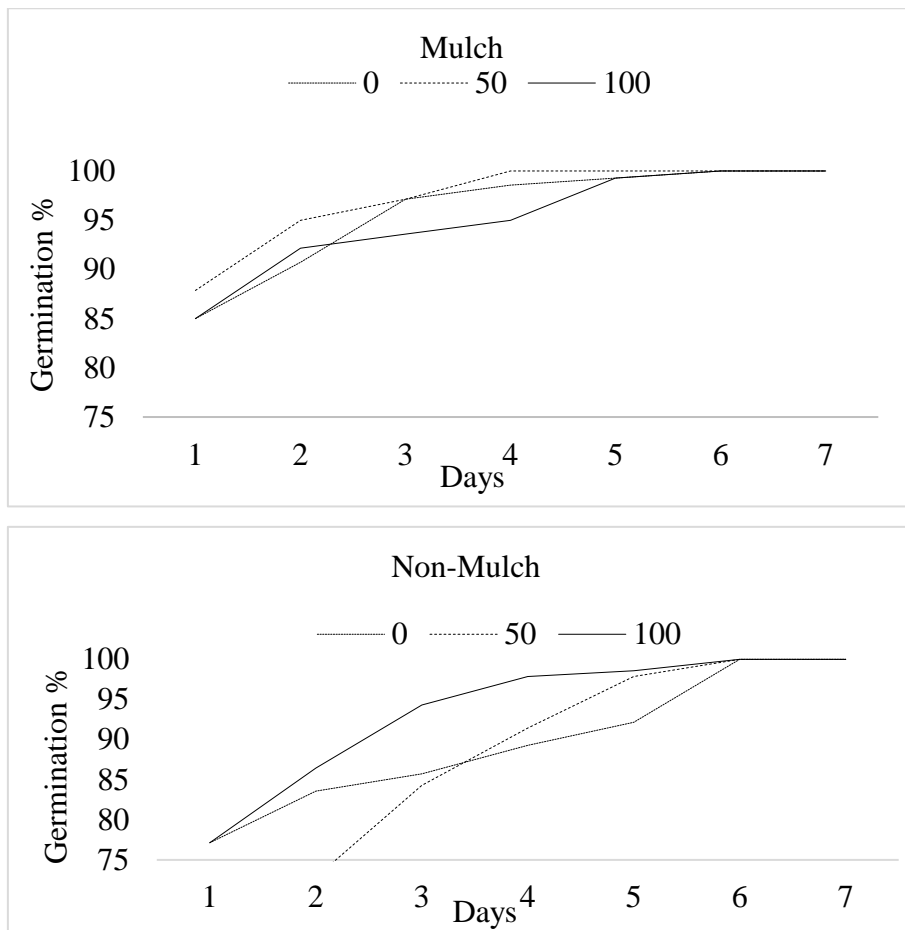


Figure 5.4: The effect of mulching treatment and fertiliser rate on the mean germination percentage of soybean.

Table 5.2: A comparison of soybean seed quality parameters in response to mulching and fertiliser treatments under germination test showing mean germination time (MGT), germination velocity index (GVI) and seedling parameters.

Mulch Treatment	Fertiliser rate	MGT(days)	GVI	Seedling Length	Shoot Length	Root Length	Ratio	Fresh	Dry
NM	0%	2.4a	3.43.a	9.8ab	4.62a	5.2a	1.62a	1.781a	0.24a
	50%	3.76a	3.021a	13.4ab	6.43ab	7.28ab	1.832a	1.67a	0.27a
	100%	2.2a	2.15a	15.67ac	7.75ab	8.41ab	2.52a	1.88a	0.211a
	Mean	2.78	2.87	13.9	6.7	7.2	2.34	1.57	0.423
HM	0%	1.2a	2.11a	11.09ab	5.32a	6.75ab	2.9a	1.46a	0.3a
	50%	1.3a	1.7a	12.82ab	4.86a	8.94ab	2.5a	1.92a	0.25a
	100%	1.05a	1.51a	15.73ac	5.43a	10.68ac	3.2a	1.76a	0.21a
	Mean	1.18	1.77	13.21	5.20	8.79	2.86	1.69	0.76
P _(0.05)		<0.01	<0.01	0.071	0.061	0.23	<0.01	0.0641	0.3
LSD _(0.05)		0.46	0.24	0.35	3.2	2.26	2.43	2.13	1.5
CV%		4.1	4.64	3.6	4.3	6.1	1.3	6	3.1

*MGT – Mean Germination Time; **GVI – Germination Velocity Index

5.3 Discussion

The observed results on soybean seed germination show that limited water to the mother-plant during growing season has no effect on the seed quality assessed by germination. The pre-planting germination results indicated that the seed lot had a high seed quality with a good germination for crop stand when grown on outside environment given the conditions are conducive enough for germination and growth. The subsequent seed germination showed seed performance to be more related to the mulching treatment and rate of fertiliser (Figure 5.4). A 50% fertiliser rate under hay mulch conditions resulted in seeds having a highest germination rate and 100% fertiliser rate having the least germination. Under non-mulch conditions the same 50% fertiliser rate had the lowest seed germination percentage and the 100% fertiliser rate had the highest. The mean germination time indicates that this soybean cultivar would take 24 hours (a day) to reach 50% germination. In the results of the subsequent seed quality it was observed to be significantly different, seeds under hay-mulch conditions and non-mulched conditions both germinated to reach the accepted seed germination percentage of 90%. Non-mulch had a higher germination percentage (96%) compared to hay-mulch (89%). The average mean germination time varied significantly for mulching treatment hay-mulch and non-mulch had 1.18 and 2.78 respectively. The germination velocity index also varied significantly hay-mulch and non-mulch had 1.77 and 2.87 respectively. This indicates that the seed metabolic was retarded by limited water stress, even though seeds produced under hay-mulch had lower germination percentage but these seeds would take a day to reach half germination compared to seeds produced under non-mulch taking more than a day. Time taken by a seed to germinate and reach full emergence in field conditions is an important factor for farmers to consider. An early germinating seed is able to escapes any abiotic stress factors that can inhibit its germination to emergence. It is doubtful that limited water availability on the mother-plant would have direct impact on the metabolic activity of a seed that would subsequently affect its quality to produce a subsequent plant even though limited water can significantly reduce grain yield. It is observed that water limitations during whole growing season had no significant effects on seed quality and vigour of soybean seeds assessed by germination test but significant effect were observed on the growth and yield of soybean.

The important purpose of farmers to retain seeds is to preserve crops from one season to another. However, storage temperature and moisture content affect seed longevity with seed moisture content being more influencing than temperature (Alhamdan et al., 2011). The significant differences observed for water activity of subsequent seeds from non-mulch mother-plant had higher water activity with an average of 0.535 compared to hay-mulch mother-plant subsequent

seeds (Figure 5.2) relates to non-mulched seeds having a higher germination than hay-mulched seeds indicating that the non-mulched seeds had a higher amount of water for the hydration of nutrients in the seeds and so increasing its quality. Observed results on seed grain moisture were not significant for the mulching treatment but highly significant for fertiliser rates. A higher grain moisture content percentage of 11% was observed for seeds that were grown under 50% fertiliser rate and on the other hand, equal results were observed for seeds that were grown under 0% and 100% fertiliser rate, both had 10% grain moisture content. Knowing the seed moisture contents helps to determine the optimum time for harvest and identify appropriate seed storage conditions and drying recommendations (Crankshaw et al., 2001; Casagrande et al., 2009). This also helps establish the susceptibility of seeds toward mechanical damages and the potential for invasion by pathogens and insects. Decrease in seed quality is mostly dependent on seed moisture content, duration of storage, type of seed and seed quality. Seed moisture content is the most critical factor affecting seed quality and storage life. The seed moisture content is the amount of water in the seed, expressed as a percentage or weight basis in seed-testing laboratory. A small change in seed moisture content has a large effect on the storage life of the seeds. Seeds viability decrease more rapidly at high moisture content because of factors such as mould growth, temperature damage and humidity. The optimum moisture percentage depends on the species and the temperature. Cereals should have moisture content at 13 % or below, legumes at 10%. However some legumes seed can be easily damaged if the seed is too dry. The lower the seed moisture percentage is, the slower the rate of seed respiration. A slower rate of seed respiration results in a slower rate of deterioration. Therefore, proper drying of the seed is critical for minimizing deterioration during storage. Different crops absorb different amounts of water. Seeds high in protein and starch typically possess higher equilibrium seed moisture content at the same relative humidity compared to seeds high in oil content.

5.4 Conclusion

The objective of the study was to evaluate the effect of mulch and fertiliser on soybean seed quality. From the observed findings, it can be concluded that mulching treatment and fertiliser rates used had no significant effect on the seed quality accessed by germination percentage, water activity and grain moisture content of the seeds. Furthermore, limited water availability during crop growth does not affect the seed attributes to seed quality factors evaluated on this study but can have significant reduction in crop growth and yield.

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CHAPTER 6

6.1 General Discussion

Sub-Saharan Africa is at the epicentre of the effect of climate change and variability. Rainfall variability continues to be a significant constraint to the sustainability of rain-fed cropping across the region. Climate change projections suggest that rainfall will decrease in most part of SSA, with increasing variability and extremes such as drought and floods. Currently, smallholder farmers in the region are most vulnerable as they are resource poor and often lack the capacity to adapt. There is a need to develop strategies that can help farmers cope with increasing rainfall variability, in the short-term, and acquire long-term adaptation to climate change. In this regard, climate smart agricultural techniques are being promoted to smallholder farmers in the rural areas in SSA. Other than water availability, another constraint to production for farmers in rural areas is poor fertility soils. Most rural areas are located on marginal lands with inherent poor soil fertility. Given that farmers often lack the means to afford fertilisers, yields are also comprised by poor soil fertility. Therefore, strategies to assist farmers cope with limited water availability should also pay attention to integrated soil fertility management.

For the current study, the use of mulching was considered as a strategy for improving soil water retention in the field. Concurrently, soybean, a legume crop capable of fixing atmospheric nitrogen, was also considered together with the use of different fertiliser rates. Soybean production presents a great potential for improving livelihoods of resource constrained farmers as it can grow well with limited fertilisers, fix N that can boost production of associated cereals and its market value and demands are high making it a good cash crop.

Introduction of mulching use strategy to smallholder farming systems was effective in mitigating losses to runoff and soil evaporation losses. This was evidenced by the higher soil water content that was observed in mulched relative to non-mulched plots. However, contrary to expectations, increased soil water retention and water availability in the root zone did not translate to notable gains in soybean productivity. Results showed no significant differences in plant growth, physiology and ultimately yield between mulched and non-mulched plots. Interestingly, plants grown under non-mulched plots showed better growth for parameters such as leaf number. A possible reason for this could have been the effect of mulching on the soil temperature and the immediate micro-climate around the crop canopy. The layer of mulching resulted in low soil temperatures which affected soil water uptake, while the mulch might have increased the relative humidity around the canopy thus suppressing gaseous exchange. This

hypothesis was supported by the observed lower stomatal conductance in mulched plots relative to non-mulched plots. Given that stomatal conductance is directly correlated to biomass production, hence yield, the effect of suppressed stomatal conductance would have resulted in suppressed growth and subsequently yield as well.

A secondary objective of the study was to determine the effect of fertiliser on growth and yield of soybean. The expectation was that both growth and yield would increase with increasing fertilisation. However, results did not show any statistically significant differences between fertiliser treatments. The effect of fertiliser was only observed for grain moisture content where 50% fertiliser rate had significantly higher grain moisture content compared to 0% and 100% fertiliser rates, respectively.

6.2 Conclusion

The objective of the study was to determine the effect of using a grass mulch and fertiliser on soil water content, growth and yield of soybean. Therefore it is concluded that mulch treatment and fertiliser use had no effect on increasing soybean growth and yield. Mulching was effective in reducing water losses through the runoff and soil evaporation hence increasing soil water availability in the root zone. However, the gains in soil water availability did not translate to higher yield. Similarly, increasing fertiliser rates did not translate to improvements in yield of soybean. A future study should focus on increasing the range of measured variables in order to fully explain the effects of mulching on soil temperatures, root-soil-water uptake and the micro-climate around the canopy.

6.3 Recommendations

- In the short-term, the use of mulch is recommended as a soil water retention strategy, and
- Soybean production is possible under smallholder farmer conditions.

APPENDICES

Appendix 1: ANOVA Tables

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4650280.	2325140.	0.97	
Rep. Mulching treatment stratum					
Mulching treatment	1	2350660.	2350660.	0.98	0.426
Residual	2	4784523.	2392261.	1.03	
Rep. Mulching treatment. Fertiliser level stratum					
Fertiliser level	2	4653445.	2326723.	1.00	0.410
Mulching treatment. Fertiliser level					
	2	4681175.	2340587.	1.01	0.408
Residual	8	18624552.	2328069.	0.99	
Rep. Mulching treatment. Fertiliser level					
WAP	8	19556946.	2444618.	1.04	0.412
Mulching treatment. WAP	8	18810993.	2351374.	1.00	0.441
Fertiliser level. WAP	16	37623592.	2351475.	1.00	0.464
Mulching treatment. Fertiliser level. WAP					
	16	37617156.	2351072.	1.00	0.464
Residual	96	225757369.	2351639.		
Total	161	379110690.			

Variate: Leaf number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	66.52	33.26	3.08	
Rep. Mulching treatment stratum					

Mulching treatment	1	192.59	192.59	17.82	0.052
Residual	2	21.61	10.81	0.64	

Rep. Mulching treatment. Fertiliser level stratum

Fertiliser level	2	3.46	1.73	0.10	0.904
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Mulching treatment. Fertiliser level

	2	67.91	33.96	2.01	0.196
Residual	8	134.93	16.87	1.61	

Rep. Mulching treatment. Fertiliser level. *Units* stratum

WAP	8	3174.53	396.82	37.90	<.001
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Mulching treatment. WAP	8	179.66	22.46	2.14	0.039
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Fertiliser level. WAP	16	60.30	3.77	0.36	0.988
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Mulching treatment. Fertiliser level. WAP

	16	173.12	10.82	1.03	0.430
Residual	96	1005.14	10.47		

Total 161 5079.79

Variate: Stomatal conductance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
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Rep stratum	2	1439.	719.	0.83	
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Rep. Mulching treatment stratum

Mulching treatment	1	2375.	2375.	2.73	0.241
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Residual	2	1743.	872.	0.38	
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REP. Mulching treatment. Fertiliser level stratum

Fertiliser level	2	1455.	728.	0.32	0.737
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Mulching treatment. Fertiliser level

	2	1075.	538.	0.23	0.797
Residual	8	18379.	2297.	1.46	

REP. Mulching treatment. Fertiliser level stratum					
DATE	9	71951.	7995.	5.07	<.001
Mulching treatment. Date	9	27231.	3026.	1.92	0.057
Fertiliser level. Date	18	17940.	997.	0.63	0.868
Mulching treatment. Fertiliser level. Date					
	18	13484.	749.	0.47	0.964
Residual	108	170409.	1578.		
Total 179 327481.					

Variate: Chlorophyll Content Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1598.	799.	0.83	
Rep. Mulching treatment stratum					
Mulching treatment	1	2639.	2639.	2.73	0.241
Residual	2	1937.	968.	0.38	
Rep. Mulching treatment. Fertiliser level stratum					
Fertiliser level	2	1617.	808.	0.32	0.737
Mulching treatment. Fertiliser level					
	2	1195.	597.	0.23	0.797
Residual	8	20421.	2553.	1.46	
REP. Mulching treatment. Fertiliser level stratum					
WAP	8	26967.	3371.	1.93	0.065
Mulching treatment. WAP	8	37698.	4712.	2.69	0.010
Fertiliser level. WAP	16	17778.	1111.	0.63	0.848
Mulching treatment. Fertiliser level.WAP					
	16	13364.	835.	0.48	0.953
Residual	96	168014.	1750.		
Total	161	293228.			

Variate: Leaf Area Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.4089	0.2045	5.10	
Reps. Mulching stratum					
Mulching	1	0.1226	0.1226	3.06	0.222
Residual	2	0.0801	0.0401	0.20	
Reps. Mulching. Fertiliser stratum					
Fertiliser	2	1.2379	0.6190	3.06	0.103
Mulching. Fertiliser	2	0.5430	0.2715	1.34	0.314
Residual	8	1.6187	0.2023	1.49	
Reps. Mulching. Fertiliser stratum					
WAP	5	3.0637	0.6124	2.35	0.211
Mulching. WAP	5	1.0755	0.2151	1.58	0.185
Fertiliser. WAP	10	2.0375	0.2037	1.50	0.173
Mulching. Fertiliser. WAP	10	0.8177	0.0818	0.60	0.805
Residual	45	6.1301	0.1362		
Total	92	45.1860			

Variate: Total Biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5564.	2782.	1.72	
Rep. Mulching stratum					
Mulching	1	1895.	1895.	1.17	0.392
Residual	2	3239.	1620.	1.26	

Rep. Mulching. Fertiliser stratum					
Fertiliser	2	2861.	1431.	1.11	0.374
Mulching. Fertiliser	2	2932.	1466.	1.14	0.366
Residual	8	10272.	1284.		
Total 17 26763.					

Variate: Plant number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	308.8	154.4	4.13	
Rep. Mulching stratum					
Mulching	1	93.4	93.4	2.50	0.255
Residual	2	74.8	37.4	0.20	
Rep. Mulching. Fertiliser stratum					
Fertiliser	2	452.8	226.4	1.21	0.347
Mulching. Fertiliser	2	631.4	315.7	1.69	0.244
Residual	8	1493.1	186.6		
Total 17 3054.3					

Variate: Pod Number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	27785.	13893.	2.44	
Rep. Mulching stratum					
Mulching	1	2616.	2616.	0.46	0.568
Residual	2	11372.	5686.	0.96	
Rep. Mulching. Fertiliser stratum					

Fertiliser	2	5897.	2949.	0.50	0.625
Mulching. Fertiliser	2	10187.	5094.	0.86	0.458
Residual	8	47298.	5912.		
Total	17	105157.			

Variate: Seed number

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	41445.	20723.	0.87	
Rep. Mulching stratum					
Mulching	1	30013.	30013.	1.27	0.377
Residual	2	47385.	23693.	2.43	
Rep. Mulching. Fertiliser stratum					
Fertiliser	2	55156.	27578.	2.83	0.118
Mulching. Fertiliser	2	16561.	8281.	0.85	0.463
Residual	8	77974.	9747.		
Total	17	268534.			

Variate: Seed weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	301.51	150.75	0.40	
Rep. Mulching stratum					
Mulching	1	19.26	19.26	0.05	0.842
Residual	2	749.20	374.60	4.84	
Rep. Mulching. Fertiliser stratum					
Fertiliser	2	534.49	267.25	3.45	0.083

Mulching. Fertiliser	2	87.36	43.68	0.56	0.590
Residual	8	618.81	77.35		
Total	17	2310.63			

Variate: Pre-Germination

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1750.14	583.38	17.74	
Rep.					
Day	6	5186.71	864.45	26.29	0.8
Residual	18	591.86	32.88		
Total	27	7528.71			

Variate: Germination

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	57.726	19.242	0.57	
Rep. Mulching Treatment stratum					
Mulching Treatment	1	1471.137	1471.137	43.25	0.007
Residual	3	102.041	34.014	1.27	
Rep. Mulching Treatment. Fertiliser level stratum					
Fertiliser level	2	134.791	67.396	2.51	0.123
Mulching Treatment. Fertiliser level					
	2	515.160	257.580	9.60	0.003
Residual	12	321.866	26.822	3.20	
Rep. Mulching Treatment. Fertiliser level stratum					
Day	6	8593.780	1432.297	170.71	<.001

Mulching Treatment. Day	6	1037.707	172.951	20.61	<.001
Fertiliser level. Day	12	282.896	23.575	2.81	0.002
Mulching Treatment. Fertilizer level. Day					
	12	661.710	55.143	6.57	<.001
Residual	108	906.122	8.390		
Total	167	14084.937			

Variate: Water Activity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.0009314	0.0004657	0.92	
Rep. Mulching treatment stratum					
Mulching treatment	1	0.0109405	0.0109405	21.67	0.043
Residual	2	0.0010098	0.0005049	0.47	
Rep. Mulching treatment. Fertilizer level stratum					
Fertiliser level.	2	0.0018492	0.0009246	0.86	0.459
Mulching treatment. Fertiliser level.					
	2	0.0011520	0.0005760	0.54	0.605
Residual	8	0.0086077	0.0010760	4.07	
Rep. Mulching treatment. Fertiliser level stratum					
	90	0.0237942	0.0002644		
Total	107	0.0482848			

Variate: Grain Moisture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
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Rep. stratum	2	0.0504	0.0252	0.01	
Rep. Mulching treatment stratum					
Mulching treatment	1	0.0110	0.0110	0.00	0.950
Residual	2	4.4214	2.2107	1.86	
Rep. Mulching Treatment. Fertiliser level stratum					
Fertiliser level.	2	12.2613	6.1307	5.16	0.036
Mulching treatment. Fertiliser level stratum					
	2	1.7716	0.8858	0.75	0.505
Residual	8	9.5032	1.1879	3.96	
Rep. Mulching treatment. Fertiliser level stratum					
	90	27.0177	0.3002		
Total	107	55.0367			

